3/15/20

REPORT No. 63

RESULTS OF TESTS ON RADIATORS FOR AIRCRAFT ENGINES

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

PREPRINT FROM FIFTH ANNUAL REPORT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

3153
45

REPORT No. 63

RESULTS OF TESTS ON RADIATORS FOR AIRCRAFT ENGINES

▽

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

PREPRINT FROM FIFTH ANNUAL REPORT

▽

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

REPORT No. 63

RESULTS OF TESTS ON RADIATORS FOR AIRCRAFT ENGINES

Part I.—HEAT DISSIPATION AND OTHER PROPERTIES OF RADIATORS

By H. C. DICKINSON, W. S. JAMES, and R. V. KLEINSCHMIDT

Part II.—WATER FLOW THROUGH RADIATOR CORES

By W. S. JAMES

REPORT No. 63.

PART I.

HEAT DISSIPATION AND OTHER PROPERTIES OF RADIATORS.

By H. C. Dickinson, W. S. James, and R. V. Kleinschmidt.

INTRODUCTION.

The present report is the fourth of a series of reports on airplane radiators, incorporating the results of experimental work at the Bureau of Standards under the joint auspices of that Bureau, the Aviation Departments of the Army, and the National Advisory Committee for Aeronautics. The first three are the following:

Technical Report No. 43, Synopsis of Aeronautic Radiator Investigations for the years 1917–1918;

Technical Report No. 59, General Analysis of the Airplane Radiator Problem; and

Technical Report No. 60, General Discussion of Test Methods for Radiators.

These reports contain a discussion of the technical terms used and briefly defined in the present report, and a discussion of the methods used in obtaining the data on which the present report is based.

PURPOSE.

The purpose of this report is to present the results of tests on 56 types of core in a form convenient for use in the study of the performance of and possible improvements in existing designs. Working rules are given by which the data contained in the report may be used, and the most obvious conclusions as to the behavior of cores are summarized.

DEFINITIONS OF TERMS.

(For a complete discussion of the terms and their significance, see the "Analysis," Technical Report No. 59.)

I. CHARACTERISTICS WHICH DESCRIBE A TYPE OF CORE.

These characteristics are given in Table I, and a few of the most important are included on each curve sheet.

Metal is designated as brass or copper without attempting to gave exact composition. The thickness is approximate to 0.001 inch.

Dimensions of core.—Length is measured in the general direction of the water flow; depth, in the general direction of air flow; and width perpendicular to these two.

Dimensions of water tubes.—Length (in the direction of water flow) is expressed in inches per foot length of core; depth is measured in the same direction as depth of core; and width is the thickness of the stream of water.

Cooling surface is regarded as direct only when backed by flowing water. Indirect surface includes fins, spacers, and surface backed by stagnant water.

Per cent free area is the cross-sectional area of the air tubes in per cent of the frontal area.

All characteristics are given for a section of core 1 foot square.

II. PROPERTIES THAT DESCRIBE THE PERFORMANCE OF A CORE.

The properties of a core are obtained primarily for the purpose of comparing cores. It must be remembered that the properties of a complete radiator on a plane depend, not only upon the properties of the core but on the location of the radiator on the plane. This is especially true of head resistance and the properties involving it. (The method of estimating the probable performance of a radiator from the properties of its core is given under "Use of the data in designing a radiator," below.)

Mass flow of air through the core is expressed in pounds per second per square foot of frontal area. When a core is supported in a free air stream, the flow of air through it is proportional to the free air speed (for ordinary types of core).

The mass flow constant is the ratio between the mass flow through the core, and the mass of air flowing through a square foot of area normal to the direction of flow in the undisturbed air stream. For some purposes it is more convenient to use a "mass flow factor" which is the factor by which free air speed in miles per hour must be multiplied to obtain mass flow.

Energy dissipated or heat transfer is expressed in horse power per square foot of frontal area, for a difference of 100° F. between the temperature of the air entering the radiator and the mean of the temperature of the entering and leaving water.

Head resistance of the core is the force required to push it through the air, and is expressed in pounds per square foot of frontal area.

Head resistance constant is the factor by which the square of the free air speed in miles per hour must be multiplied to obtain head resistance in pounds per square foot.

Horsepower absorbed is computed by adding to the head resistance the quotient obtained by dividing the weight of core and contained water (in pounds per square foot front) by the lift-drift ratio of the airplane, and multiplying the sum by the speed of the plane and by a conversion factor.

As the lift-drift ratio varies between different planes and varies even more widely between climbing and level flight, it is very important to consider, in the selection of a core, the relative importance of climbing speed and top speed. The value 5.4 is used throughout this report as a good average for planes and gives equal weight to rate of climb and top speed. If rate of climb is of prime importance the value should be as low as 3, while if speed on the level is the most important a value as high as 10 may be used.

Figure of merit is the ratio of the energy dissipated in horsepower to the horsepower absorbed.

Pressure necessary to produce water flow is of importance in determining the maximum flow possible through a given type of core.

CONDITIONS UNDER WHICH THE CORE OPERATES.

As the properties of a core vary with the conditions under which it is used, it is necessary to express the results of tests in terms of certain definite conditions adopted as standard. The conditions adopted in this work are:

1. *Water flow* must be high enough to insure turbulent flow. For most types of core this means that it must be above about 2 gallons per minute per inch of core depth per foot width of core.

2. *Temperature difference* (between entering air and mean water temperature) of 100° F. is used in computing the heat transfer and figure of merit as given.

3. *Air density* is taken as 0.0750 pounds per cubic foot. All results given in this report are reduced to these conditions.

Since one of the most important conditions affecting radiator performance is the mass flow of air through the core, the properties of the cores have been expressed in terms of mass flow.

The effects of variation from the conditions adopted as standard are treated in detail in separate reports, but are mentioned below in a form for use in design.

GENERAL FACTS DEDUCED FROM THE RESULTS OF EXPERIMENTS.

General statements deduced from the results of the experiments, together with a few of the most important conclusions from other reports, are as follows:

HEAT TRANSFER.

1. Heat transfer is a function of *mass flow of air*, independent of density. (See Technical Report No. 62.)

2. Heat transfer is roughly proportional to *mass flow* for a core having only *direct cooling surface*. When there is a considerable amount of indirect cooling surface the heat transfer increases less rapidly than mass flow at high air speeds.

3. Heat transfer is proportional to the *temperature difference* mentioned above.

4. Heat transfer is not greatly affected by the *rate of water flow* provided the rate is above 2 gallons per minute per inch of core depth per foot width of core. It should be noted, however, that this is true only when the mean water temperature is regarded as constant. (See below, "Use of data in the design of radiator: Rate of water flow.")

5. Heat transfer from *direct* cooling surface is not appreciably affected by the *composition of the metal.* When fins and other indirect cooling surface are used the thermal conductivity of the metal is important.

6. Heat transfer is somewhat increased, but at the expense of a large increase in head resistance, by spirals or other forms of passages which increase the turbulence of the air stream. Heat transfer is greater for smooth than for rough tube walls, for, if the surface is rough, it will be covered with a layer of more or less stagnant fluid.

HEAD RESISTANCE.

1. Head resistance for any particular core varies approximately as the square of the *free air speed.* In most cases the exponent is slightly less than 2. Radiator E–4 is an exception to this rule. This radiator exhibits resonance effect which causes it to whistle in an air stream having a velocity of more than about 30 miles per hour, and cause head resistance curve to show irregularities in the region where whistling starts.

2. The head resistance of a core appears to be closely related to its mass constant so that, in general, anything which tends to cut down the flow of air through the core will cause a considerable increase in head resistance. (See plot 1.)

3. Head resistance varies directly as the *air density* for a given free air speed, and inversely as the density for a given mass flow. (See Technical Report No. 62.)

4. Head resistance is considerably increased by projections, indentations, or holes in the air tube walls.

5. Head resistance per square foot is not appreciably affected by the *size of the core* within the limits used, viz, 8 by 8 inches to 16 by 16 inches and 12 by 24 inches. (See Technical Report No. 61, Part I.)

MASS FLOW OF AIR.

Mass flow of air is directly proportional to *free air speed* for most types of core. The cores E–4 and G–4 are exceptions.

USE OF THE DATA IN THE DESIGN OF A RADIATOR.

CHOICE OF A POSITION.

The first step in the design of a radiator is the choice of a position on the airplane. The possible positions may be divided into two classes:

1. Unobstructed positions; i. e., those in which the flow of air through and around the radiator is not obstructed by other portions of the plane.

2. Obstructed positions, such as the nose of the fuselage, a position within the fuselage, and in the plane of the wing.

It has been shown in Technical Report No. 61, and also in reports of work done both in Great Britain and in France, that an obstructed position involves a very large absorption of power, so that from the viewpoint of power absorbed for a given heat transfer, the unobstructed position is far preferable to the obstructed. Tests on a model have shown that the resistance of a fuselage fitted with a nose radiator is from two to three times the resistance of the same fuselage with a stream-line nose, and that the increase in resistance due to the substitution of a radiator for the stream-line nose is greater than the increase that would be caused by using a radiator of the same core construction and the same cooling capacity in an unobstructed position.

SELECTION OF A TYPE OF CORE.

In an unobstructed position the head resistance and consequently also the figure of merit of the *core* will be closely related to these properties of the *complete radiator,* so that in this case the core must have a high figure of merit at the free air speed at which it is used. The most compact construction consistent with this fundamental requirement is desirable. In order to obtain a high figure of merit the core should have smooth, straight air passages, easy entrances and exits for the air, and a large per cent free area. With these factors carefully attended to the figure of merit of cores increases with depth up to 20 times the diameter of the air tubes, which is as far as experiments have been made. Even greater depth may be of advantage in obtaining compactness.

By far the most satisfactory radiator for use in unobstructed positions seems to be one of thin flat plates, not over $\frac{1}{16}$ inch thick, and spaced $\frac{1}{2}$ inch on centers. The plates should be at least 12 inches in depth. The chief defect of this type of construction is mechanical weakness. (See cores E–6, E–7, and E–8.)

Of radiators now in commercial use in this country that have been tested, Nos. A–23, A–13, A–20, A–19, and A–7 are best suited to use in unobstructed positions, but they are decidedly inferior to the flat plate type at high air speeds.

For use in obstructed positions the selection of a core is more difficult, but in general high heat transfer at low air speeds is desirable. Indirect cooling surface may be of advantage if it is made of copper, crimped from the water tube walls, and well soldered to them at all possible places.

Among the cores tested, Nos. A–7, A–20, G–3, A–2, G–4, and B–8 are best suited for obstructed positions. It should be noted that for use in the wing, a high head resistance of the core is not a disadvantage, and it is possible that a core such as F–4, which has considerable mechanical strength and a low water resistance, might be used.

With this possible exception, the fin and tube type is unsuited for use in any position, its high head resistance and small amount of direct cooling surface making its efficiency very low.

SIZE OF CORE.

Having selected a type of core for the desired location, the computation of size required is relatively simple. In the case of a radiator for an unobstructed position, the heat transfer can be determined directly from the curves if the desired best climbing speed of the plane and the air temperature are known. The effect of propeller slip must be estimated and allowed for. The energy to be dissipated should be determined if possible in any particular case, but is usually about equal to the brake horsepower of the engine. Then the ratio of the energy to be dissipated to the energy dissipated per square foot frontal area of core will give the frontal area required. From the weight and head resistance the effect of the radiator on the aerodynamical properties of the plane can be determined.

In the case of a radiator placed in the nose of the fuselage, until better data are available, the mass flow of air in pounds per second per square foot may be considered numerically as between 0.04 and 0.07 times the speed of the plane in miles per hour, depending on the amount of cowling and the masking effect of the propeller. From this the mass flow can be estimated, and the energy dissipated per square foot frontal area is determined from the plots, using the mass flow scale.

The mass flow for a wing radiator depends upon the angle of incidence, but is probably not over 0.01 times the plane speed in M. P. H., even at the best climbing angle. The tubes are in this case presented to the air at an angle which probably increases the heat transfer considerably.

POWER ABSORBED.

Power absorbed can be computed readily only in the case of a radiator in an unobstructed position. The actual force on the radiator core when in an obstructed position may be computed from the curves of head resistance against mass flow, but the uncertain effect on the properties of the fuselage is of far greater importance. For obstructed radiators, the power absorbed as computed represents only the minimum possible absorption.

RATE OF WATER FLOW.

Although the energy dissipated as given in the curves is practically constant for rates of water flow above about 2 gallons per minute per foot width per inch depth of core, the allowable mean temperature increases slightly with increased water velocity, since it is the temperature of the entering water that must be kept at a certain point below boiling. With a flow of ¼ gallon per minute per horsepower dissipated a temperature difference of about 20° F. is obtained, or the mean water temperature in the radiator is 10° F. below the entering water temperature. If the flow is increased to ½ gallon per minute the temperature difference will be 10° and the mean temperature may be 5° higher than before. A further increase in water flow could not give more than 5° further increase and would probably be at the cost of an excessive loss of power in the pump. A flow of ½ gallon per minute per horsepower dissipated may be regarded as desirable, while with radiators that are relatively long and narrow a decrease of flow to ¼ gallon per minute per horsepower dissipated may be necessary.

PRESSURE NECESSARY TO PRODUCE WATER FLOW.

The pressure which is available to produce the water flow is usually the difference between the vapor pressure of the water leaving the radiator and atmospheric pressure. As this pressure difference may be only about 5 pounds per square inch, the resistance of the core to water flow may limit the possible flow seriously unless care is taken to make the core as wide as possible.

The water resistance of a core seems to depend largely on the care used in manufacture and on the form of the water tube entrances and exits. In the light of tests made, it seems that it would be well to include a test for pressure necessary to produce water flow in acceptance specifications for complete radiators, as slight variations in manufacture affect water resistance greatly. In Part II of this report are given the results of some tests on water resistance.

DESCRIPTION OF TABLES AND CURVES.

In order to indicate the degree of reliability of the results shown, actual observations are indicated on the plots by circled points, and at the end of this report is a brief statement showing the means used in obtaining results for the cases where "observed" points are not shown.

Table I contains the characteristics of cores as noted above and sketches showing the form of air and water passages. This table includes certain special types of core on which complete tests have not been made and which are accordingly not included in this report. The special properties of such cores will be made the subjects of separate reports.

Table II lists the properties of the cores at mass flows of air of 2, 4, 6, and 8 pounds per square foot per second, in order to allow ready comparison between them. It also includes the heat transfer in B. t. u. per minute per square foot of frontal area of core, and in horsepower and in B. t. u. per minute per square foot of cooling surface.

Table III lists the same properties as Table II at free air speeds of 30, 60, 90, and 120 miles per hour. In addition, it gives the mass flow (at "standard" density) corresponding to these free air speeds, and a "grade" for the radiator, grade A denoting very good performance and grade E very poor performance, among the cores tested. This table is directly applicable only to radiators in unobstructed positions.

Table IV gives constants of empirical equations for heat transfer, head resistance, and mass flow, for cores in unobstructed positions.

Plot 1 is an approximate empirical relation between the proportionality factors for head resistance and mass flow.

The remaining plots show the properties of the cores in terms of mass flow of air, with the corresponding free air speeds (for unobstructed positions) indicated by a scale added at the bottom of the sheet. For the core E–4, the mass flow is not a linear function of the free air speed, and a separate plot shows the properties in terms of free air speed. For the core G–4, the relation of mass flow to free air speed is linear above 15 miles per hour, but not below that speed, which fact accounts for what would appear to be an error in marking the free air speed scale of plot 58.

NOTE ON SOURCES OF DATA.

Because of the undesirability of removing the headers from all specimens so that head resistance could be measured directly, and because certain mechanically weak specimens became damaged before complete tests had been made, a part of the data was obtained not from direct measurement but by the methods described below.

Mass flow of air was measured in terms of free air speed on all specimens except E–7, and in this case was estimated by interpolation between the values for E–6 and E–8.

Heat transfer was measured in terms of mass flow of air on all types except the following:

F–4, estimated by interpolation between the values for two similar types of the same depth, but different spacings.

E–6, E–7, determined by correction from preliminary tests made before the apparatus was put in final form.

F–5, estimated from results obtained on a similar type of slightly different depth.

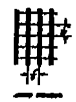
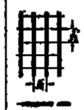
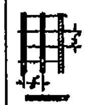
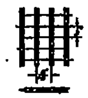
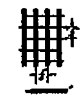
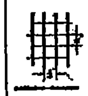
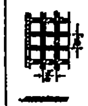
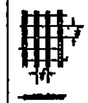
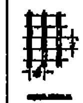
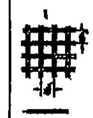
Head resistance was measured directly on half of the cores included in this report, and on a number of others not included, and the proportionality factor for head resistance was plotted against that for mass flow, in the cases of about 40 types having smooth straight air passages. The resulting points fell very near a single line, which is shown in plot 1, and this plot was used to determine head resistance from a measured mass flow factor for other types with smooth straight air passages. Values thus obtained are probably good within about 5 per cent.

The cores A–19 to A–22 and G–2 could not be treated in this way because points for similar types did not lie on the curve of plot 1, and in these cases the head resistance was estimated by comparison with other similar types and with the plot.

Head resistance of type C–2b was determined by interpolation with respect to mass flow between values for C–2 and C–2a.

Head resistance of types E–6, 7, and 8 was determined from the results of a fairly comprehensive set of tests on the head resistance of flat plate radiators of various depths and spacings.

TABLE I.—*Characteristics of radiators.*

																	
Number	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17
Depth, inches	3	3⅞	2⅝	2⅞	3	4	4⅛	2⅝	2⅞	3⅛	4½	3½	3⅝	3⅞	3	3	4
Metal:																	
Water tubes	Brass	Brass	Brass	Brass	Brass	Brass	Brass	Brass	Brass	Brass	Brass	Brass	Brass	Copper	Brass	Brass	Brass.
Fins				Copper										Copper			
Thickness of metal, inches	0.005	0.005	0.005	0.006	0.010	0.010	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006		0.004	0.004
Weight, lbs/ft.² front:																	
Empty	13.7	18.3	9.6	11.6	10.3	13.9	17.1	8.2	10.0	13.4	15.1	14.6	11.3	18.2	12.1	12.1	15.8
Water content	2.1	3.1	1.5	2.1	3.1	3.4	7.2	2.6	3.2	4.9	2.9	3.0	3.2	3.5	3.0	2.4	3.0
Filled	15.8	21.4	11.1	13.7	13.4	17.3	24.3	10.8	13.2	18.3	18.0	17.6	14.5	21.7	15.1	14.5	18.8
Per cent free area	65.5	65.7	79.6	76.5	68.0	74.9	64.2	66.2	66.8	67.8	65.6	69.2	70.4	72.1	53.0	69.8	72.1
Cooling surface, ft.²/ft.² front	39.3	51.9	30.3	28.6	36.6	49.1	62.6	30.3	37.3	51.1	61.7	39.4	43.9	46.3	35.3	34.6	47.1
Per cent direct cooling surface	44.0	44.0	46.6	44.1	47.3	46.6	52.2	47.8	47.7	54.2	48.8	40.6	50.3	48.6	42.7	48.9	43.5
Water tubes:																	
Length, in./ft. of core	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Width, inches	.045	.0471	.039	.0581	.061	.054	.078	.0641	.066		.033	.063	.0518	.054	.0545	.051	.048
Depth, inches	2.37	3.15	2.08	2.75	2.74	3.60	4.45	2.06	2.49		4.45	3.11	3.00	3.80	2.60	2.68	3.63
Number per foot	48	48	42	30	42	40	48	45	45		45	36	47	37	49	40	40
Area normal to flow, ft.²/ft	.0340	.0495	.0237	.0333	.0491	.0541	.1156	.0414	.0510		.0916	.0486	.0507	.0565	.0482	.0378	.0480
Hydraulic radius inches	.0211	.023	.019	.0286	.031	.027	.038	.0312	.032		.016	.0308	.0255	.0285	.0364	.0249	.024
Air tubes:																	
Hydraulic radius, inches	.050	.050	.063	.078	.056	.061	.050	.052	.052	.052	.051	.063	.055	.061	.047	.062	.062
Ratio, length÷hyd. rad.	58.8	78.0	38.1	37.1	53.2	65.0	97.2	45.4	54.8	75.0	92.8	55.7	61.1	63.8	63.4	48.6	64.6
Number of plot	2	3	4	5	6	7	8	9	10			11	12	13	14	15	16

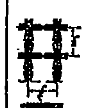
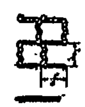
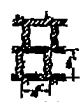
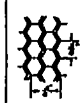
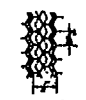
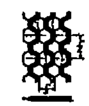
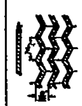
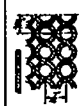
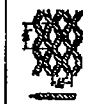
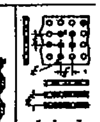
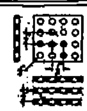
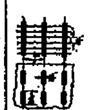
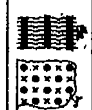
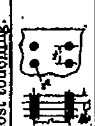
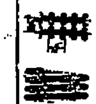
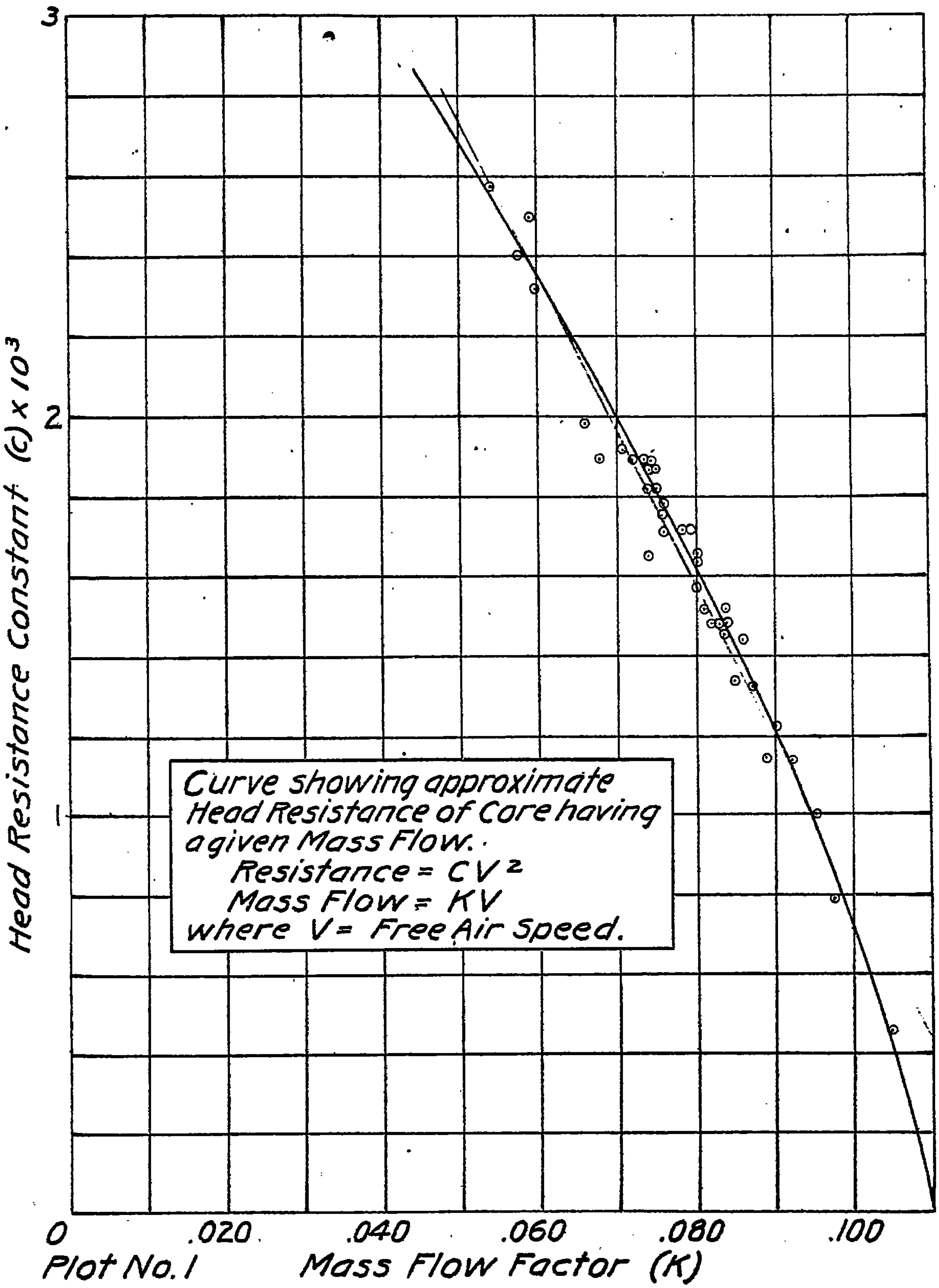
							 Indirect surface perforated.			Like B-5 to 8 but with 1/4" cells.							
Number	A-18	A-19	A-20	A-21	A-22	A-23	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9	B-10	B-11
Depth, inches	4	3	5	3	4	5	2½	4	3	3¼	2	3¼	4	5½	3½	2½	3
Metal:																	
Water tubes	Brass	Brass	Brass	Brass	Brass	Brass	Copper	Copper	Brass	Brass	Brass	Brass	Copper	Brass	Brass	Brass	Brass.
Fins																	
Thickness of metal, inches	0.004	0.005	0.005	0.009	0.005	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.005
Weight, lbs./ft.² front.																	
Empty	8.9	13.8	22.9	9.3	12.5	15.6	6.70	10.7	9.3	12.3	5.5	8.8	10.7	13.9	10.4	7.4	8.9
Water content	2.9	3.1	5.4	3.5	4.3	6.3	1.06	.63	2.0	2.1	1.0	1.7	2.3	4.2	4.0	3.1	3 9
Filled	11.8	16.9	28.3	12.8	16.8	21.9	7.76	11.3	11.3	14.4	6.5	10.5	13.0	18.1	14.4	10.5	12.8
Per cent free area	83.0	67.7	66.9	65.6	66.6	68.5	83.6	88.0	79.6	72.7	81.2	79.0	77.0	73.3	65.1	65.1	65.1
Cooling surface, ft.²/ft.² front	27.6	40.3	66.8	31.5	42.5	54.5	21.6	36.1	26.8	87.2	23 8	87.9	45.8	56.1	36.2	25.5	30.4
Per cent direct cooling surface	46.7	86.9	92.1	86	91	91.8	37.5	34.6	58.6	28.0	27.8	26.7	27.7	80.8	66.5	62.7	64.8
Water tubes:																	
Length, in./ft. of core	12.0	24.0	24.0	24.0	24.0	24.0	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	14.8	14.8	14.8
Width, inches	.089	.028	.028	.041	.0348	.0402	.056	.019	.043	.051	.0524	.057	.062	.0822	.00788	.079	.082
Depth, inches	3.65	2.64	4.63	2.59	3.67	4.64	2.21	3.78	2.68	2.88	1.73	2.68	3.40	4.84	30.6	2.03	2.50
Number per foot	21	48	48	39	39	39	17	18	30	29	22	22	22	21	31	36	36
Area normal to flow, ft.²/ft	.0459	.0249	.0435	.0284	.0348	.0505	.0148	.0087	.0276	.0295	.0139	.0282	.0315	.0597	.521.	.0402	.0511
Hydraulic radius, inches	.042	.014	.014	.0199	.0178	.0199	.0270	.0091	.0245	.025	.026	.028	.0298	.040	.0886	.038	.0396
Air tubes:																	
Hydraulic radius, inches		.051	.050	.063	.063	.064	.088	.089	.060	.058	.071	.070	.070	.069			
Ratio, length÷hyd. rad.		58.9	100	47.2	63.4	78.1	28.6	45.2		61.9	28.9	46.9	57.2	76.2			
Number of plot	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33

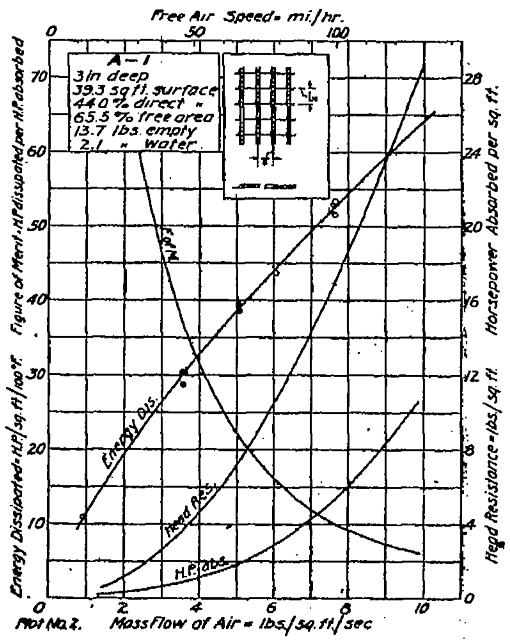
TABLE I.—*Characteristics of radiators*—Continued.

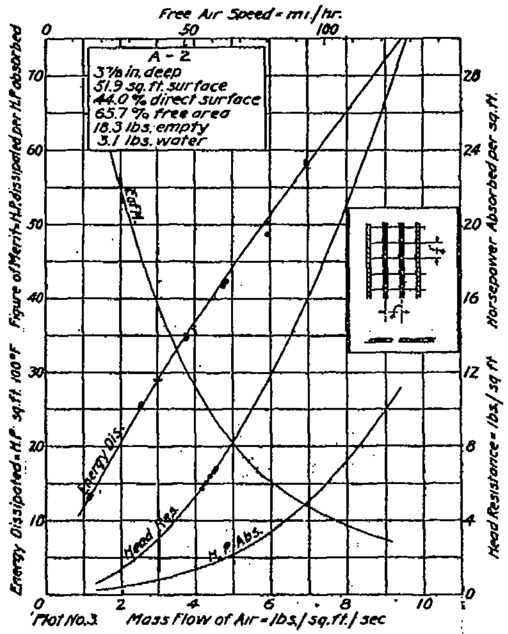
					Like C-2 with 8 inch twisted "swirlers" in cells.	Like C-2 with 2 inch swirler in one end of cells.	Like C-2 but with ⅛ inch hexagon air-tubes.	Like C-3 with 8 inch twisted swirlers.									 1/16 inch pitch. 2 sections deep.
Number	B-12	B-13	C-1	C-2	C-2a	C-2b	C-3	C-3a	C-4	C-5	C-6	C-7	D-1	D-2	D-3	D-4	E-1
Depth ... inches	3¼	4	3⅜	8⅜	8¼	8⅜	8¼	8¼	2⅞	3⅛	3	3⅛	2⅝	8	3½	3½	4¾
Metal:																	
Water tubes	Brass	Brass	Brass	Brass	Brass	Brass	Copper	Copper	Brass	Copper	Copper	Copper	Copper	Brass	Brass	Brass	Copper
Fins								Brass					Brass				
Thickness of metal ... inches	0.005	0.005	0.005	0.004	[1] .005 [2] .009	0.005	0.006	0.005	0.005	0.005	0.006	0.007	0.010	0.01	0.011	0.011	0.004
Weight, lbs./ft.² front:																	
Empty	9.6	11.9	9.6	15.7	19.2	16.7			9.2	18.3	9.1	10.5	8.5	26.9	12.8	9.1	13.6
Water content	3.9	5.4	6.6	11.5	10.7	7.6	6.2	5.0	3.9	7.1	3.6	4.1	2.2	7.2	6.2	3.9	5.2
Filled	13.5	17.3	16.2	27.2	29.9	24.8			13.1	25.4	12.7	14.6	10.7	34.1	19.0	13.0	18.8
Per cent free area	65.1	65.1	51.9	60.4	63.2	62.5	81.6	83.9	62.6	49.5	70.9	70.8	75.8	68.7			72.2
Cooling surface ... ft.²/ft.² front	34.0	41.6	82.1	48.3	76.6	56.7	51.5	64.0	82.0	35	30.4	82.5	23.7	84.1	32.6	42.0	25.0
Per cent direct cooling surface	66.2	67.6	94.2	87.2	56.3	75.9	57.3	46.9	57.2	100	46.4	46.4	46.8	44.9	83.1	42.1	89.6
Water tubes:																	
Length ... in./ft. of core	14.8	14.8	14.9	13.9	13.9	13.9	13.9	13.9	13.8	17.2	15.8	16.8	12.0	12.0			12.0
Width ... inches	.072	.079	.071	.118	.111	.118	.0781	.0695	.073	.060	.068	.088	.074	.0925		.0873	.073
Depth ... inches	2.86	3.56	3.18	7.42	7.40	7.46	7.18	7.21	2.50	3.42	2.52	3.06	2.20	7.50	2.94	2.90	2.26
Number per foot	36	36	57	25	26	26	22	20	43	55	27	25	29	24	58	29	76
Area normal to flow ... ft.²/ft.	.0512	.0705	.089	.161	.148	.1575	.0856	.0699	.0640	.079	.0320	.0468	.0348	.1155		.0610	.0824
Hydraulic radius ... inches	.035	.040	.0345	.062	.055	.062	.039	.0345	.0355	.030	.033	.0427	.038	.0459			.037
Air tubes:																	
Hydraulic radius ... inches			.055	.107					.062		.074						
Ratio, length ÷ hyd. rad			61.5	77.9					47.1		40.7						
Number of plot	34	35	36	37	38	39			40	41	42	43	44	45	46	47	

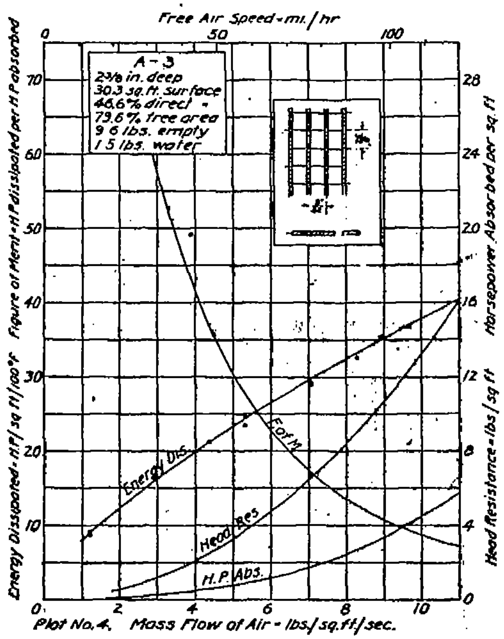
										Like F-1 but fins ⅛ inch apart.		¼ inch round tubes with ⅛ inch crimped helical, ⅛ inch pitch, staggered, fins almost touching.			Front. 	Two sections like G-2 built together back to back.	
	1/16 inch pitch. 2 sect. deep.	1/16 inch pitch. 4 sect. deep.	⅛ inch pitch. 4 sect. deep.	3/16 inch pitch. 4 sect. deep.	¼ inch pitch.	⅜ inch pitch.	½ inch pitch.										
Number	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	F-1	F-2	F-3	F-4	F-5	G-1	G-2	G-3	G-4
Depth ... inches	7⅝	9½	9½	9⅝	9¾	9¾	9¾	23½	2¾	2¾	4½	3⅝	3½	2⅝	1¾	3⅝	4
Metal:																	
Water tubes	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Brass	Copper	Copper	Copper
Fins											Brass		Brass				
Thickness of metal ... inches	0.005	0.005	0.005	0.005	0.004	0.004	0.004		0.011	0.006	0.004	0.004	0.010		0.005	0.006	0.005
Weight, lbs./ft.² front:																	
Empty	20.4	27.2	16.3	14.2	16.8	11.2	9.2	[3] 39.0					7.6	8.7	5.5	11.0	13.0
Water content	7.9	10.9	6.4	5.7	9.3	6.5	5.0	9.8	1.7	1.5	1.5	2.8	1.3	1.4	1.5	2.9	6.9
Filled	28.3	38.1	22.7	19.9	26.1	17.7	14.2	[3] 48.8					8.9	10.1	7.0	13.9	19.9
Per cent free area	71.5	71.4		88	75.0	83.3	87.5	85	76.5	74.4					74.4	72	41.2
Cooling surface ... ft.²/ft.² front	37.2	49.6	29.5	25.5	78.5	52.3	39.2	68.9	15.9	25.0	49.7	43.0	34.5	27.2	22.4	44.7	52.2
Per cent direct cooling surface	93.0	94.8	94.6	97.3	100	100	100	89.5	37.9	23.8	14.6	18.2	12.8	23.2	43.2	42.9	84.9
Water tubes:																	
Length ... in./ft. of core	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	13.1	18.1	12.0
Width ... inches	.073	.073	.073	.073	.0525	.0525	.0525	.062					.235		.0723	.069	.127
Depth ... inches	2.26	2.26	2.26	2.26	9.74	9.74	9.74	1.86					.235	1.84	1.30	1.30	3.33
Number per foot	114	152	60	80	48	32	24	176	42	42	90	72	72	29	34	68	38
Area normal to flow ... ft.²/ft.	.1264	.174	.174	.174	.170	.118	.085	.1366	.0273	.0249	.0237		.0216		.0222	.0212	.1115
Hydraulic radius ... inches	.037	.037	.037	.037	.0108	.0108	.0108	.0142	.068	.068	.059	.085	.059		.034	.033	.061
Air tubes:																	
Hydraulic radius ... inches					.0988	.156	.218										
Ratio, length ÷ hyd. rad					104	62.5	44.7										
Number of plot			48 & 49		50	51	52	53					54	55	56	57	58

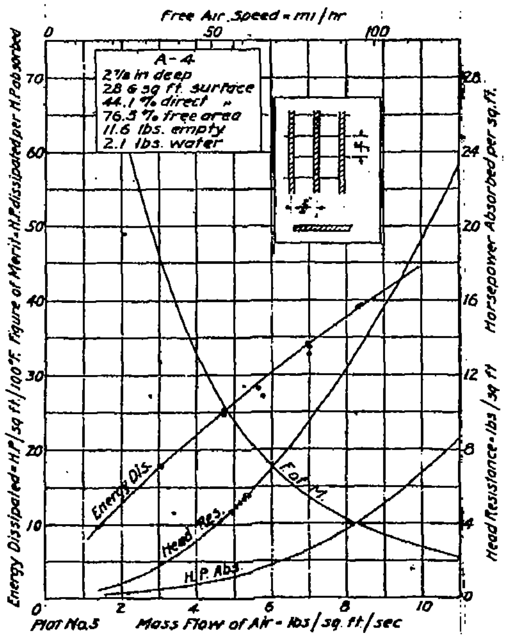
[1] Tubes. [2] Fins. [3] Estimated.

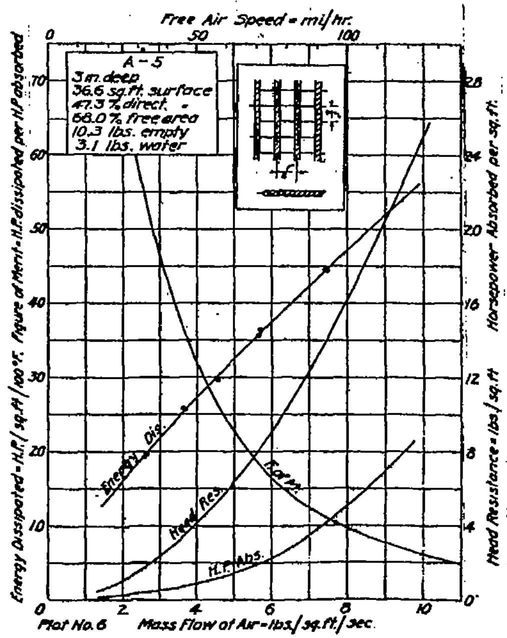

3
2
1
0
.020
.040
.060
.080
.100
Head Resistance Constant (c) x 10³
Mass Flow Factor (K)
Curve showing approximate Head Resistance of Core having a given Mass Flow.
Resistance = CV²
Mass Flow = KV
where V = Free Air Speed.
Plot No. 1

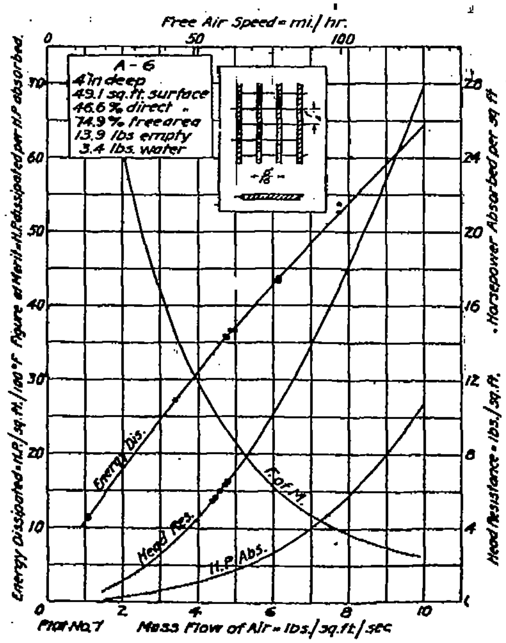

Free Air Speed = mi./hr.
A-1
3 in deep
39.3 sq.ft. surface
44.0 % direct "
65.5 % free area
13.7 lbs. empty
2.1 " water
F. of M.
Energy Dis.
Head Res.
H.P. abs.
Energy Dissipated = H.P./sq.ft./100°F. Figure of Merit = H.P. dissipated per H.P. absorbed
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 2. Mass Flow of Air = lbs./sq.ft./sec

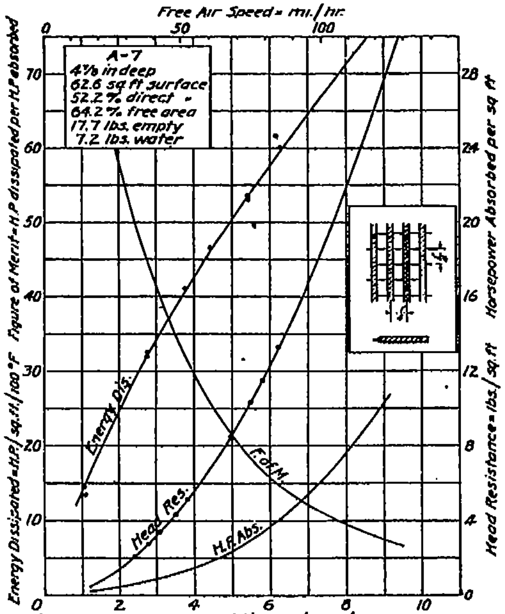

Free Air Speed = mi./hr.
A-2
3⅞ in. deep
51.9 sq.ft. surface
44.0 % direct surface
65.7 % free area
18.3 lbs. empty
3.1 lbs. water
F. of M.
Energy Dis.
Head Res.
H.P. Abs.
Energy Dissipated = H.P./sq.ft./100°F. Figure of Merit = H.P. dissipated per H.P. absorbed
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 3. Mass Flow of Air = lbs./sq.ft./sec


Free Air Speed = mi./hr
A-3
2⅞ in. deep
30.3 sq.ft. surface
46.6 % direct "
79.6 % free area
9.6 lbs. empty
1.5 lbs. water
F. of M.
Energy Dis.
Head Res.
H.P. Abs.
Energy Dissipated = H.P./sq.ft./100°F. Figure of Merit = H.P. dissipated per H.P. absorbed
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 4. Mass Flow of Air = lbs./sq.ft./sec.

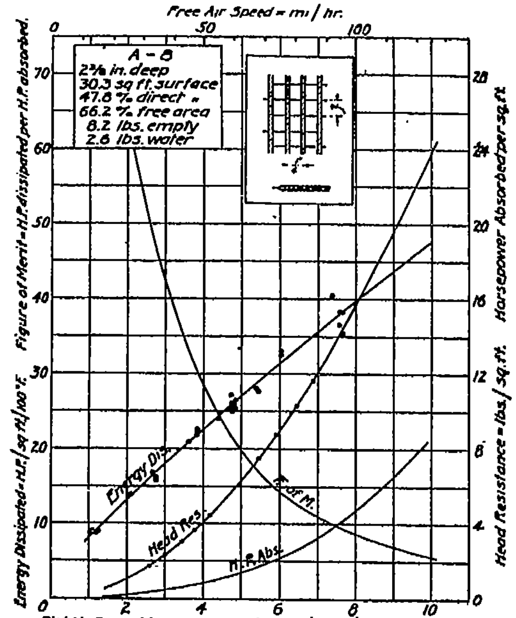

Free Air Speed = mi./hr
A-4
2⅞ in deep
28.6 sq.ft. surface
44.1 % direct "
76.5 % free area
11.6 lbs. empty
2.1 lbs. water
Energy Dis.
F. of M.
Head Res.
H.P. Abs.
Energy Dissipated = H.P./sq.ft./100°F. Figure of Merit = H.P. dissipated per H.P. absorbed
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 5 Mass Flow of Air = lbs./sq.ft./sec


Free Air Speed = mi./hr.
A-5
3 in. deep
36.6 sq.ft. surface
47.3 % direct "
68.0 % free area
10.3 lbs. empty
3.1 lbs. water
Energy Dis.
F. of M.
Head Res.
H.P. Abs.
Energy Dissipated = H.P./sq.ft./100°F. Figure of Merit = H.P. dissipated per H.P. absorbed
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 6 Mass Flow of Air = lbs./sq.ft./sec.

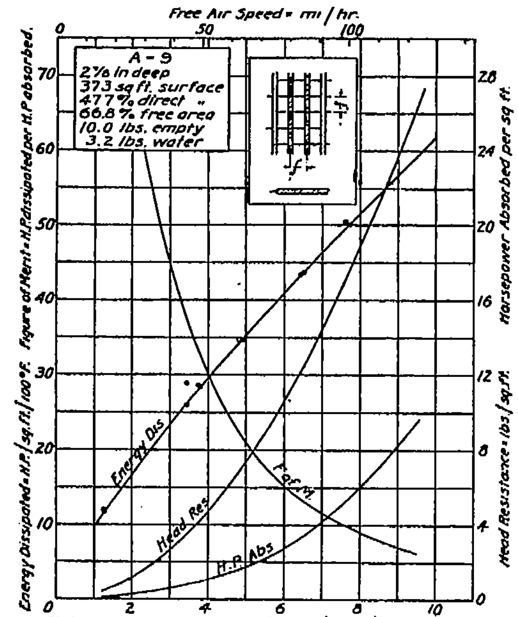

Free Air Speed = mi./hr.
A-6
4 in deep
49.1 sq.ft. surface
46.6 % direct "
74.9 % free area
13.9 lbs. empty
3.4 lbs. water
Energy Dis.
F. of M.
Head Res.
H.P. Abs.
Energy Dissipated = H.P./sq.ft./100°F. Figure of Merit = H.P. dissipated per H.P. absorbed
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 7 Mass Flow of Air = lbs./sq.ft./sec



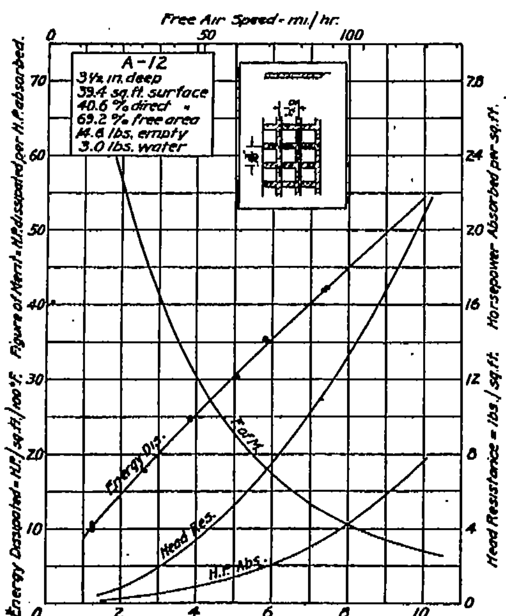
Plot No. 8



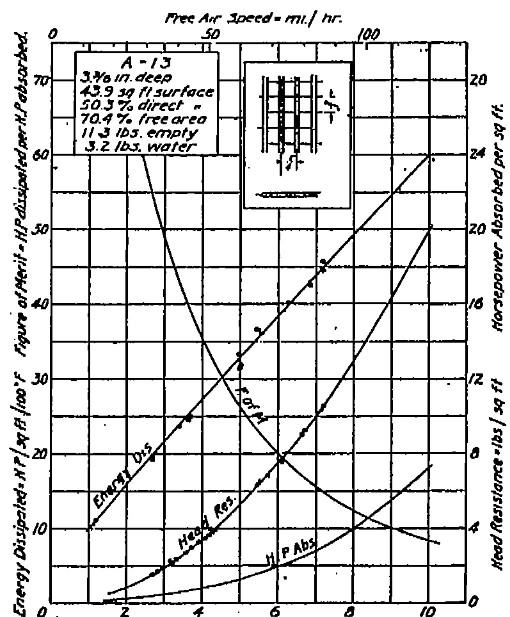
Plot No. 9



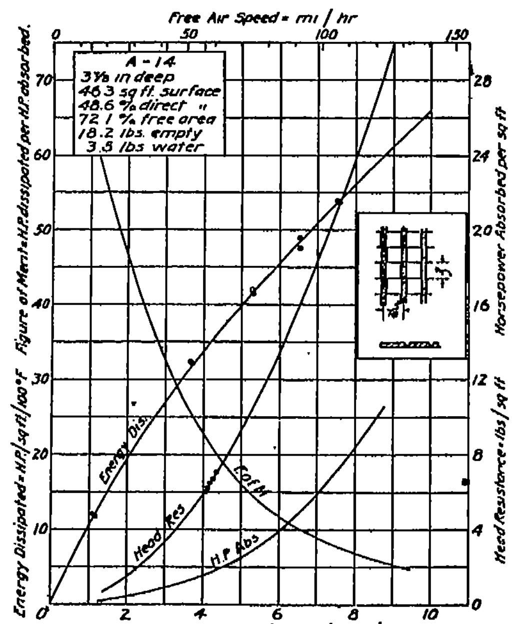
Plot No. 10



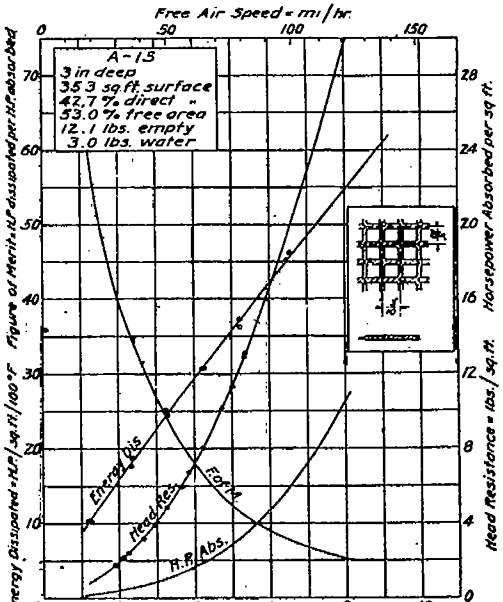
Plot No. 11



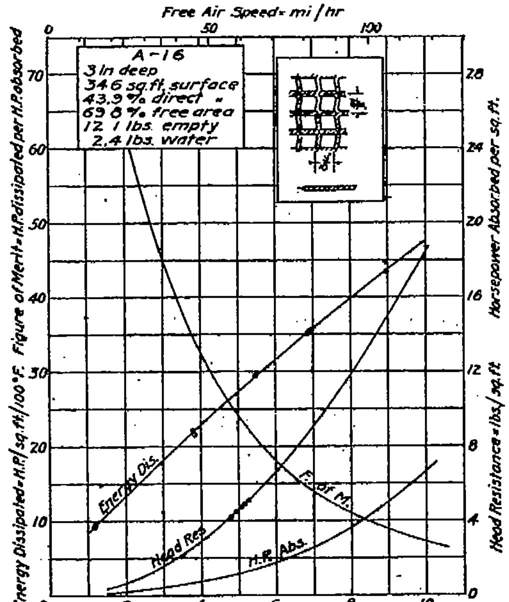
Plot No. 12



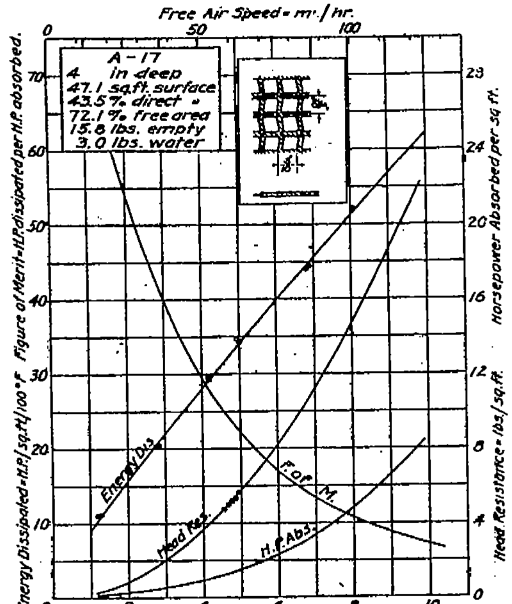
Plot No. 13



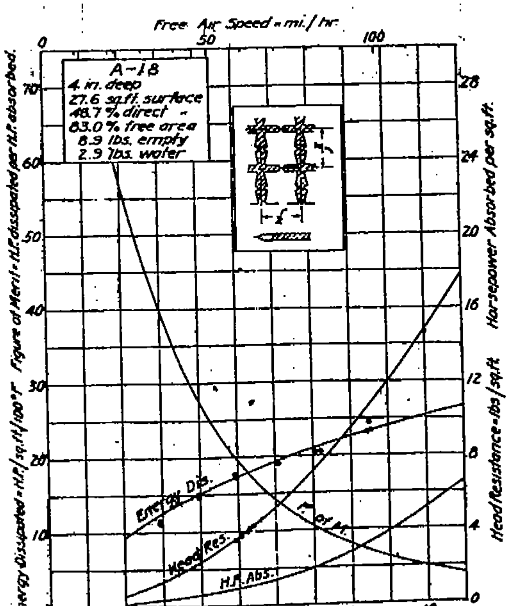
Plot No. 14



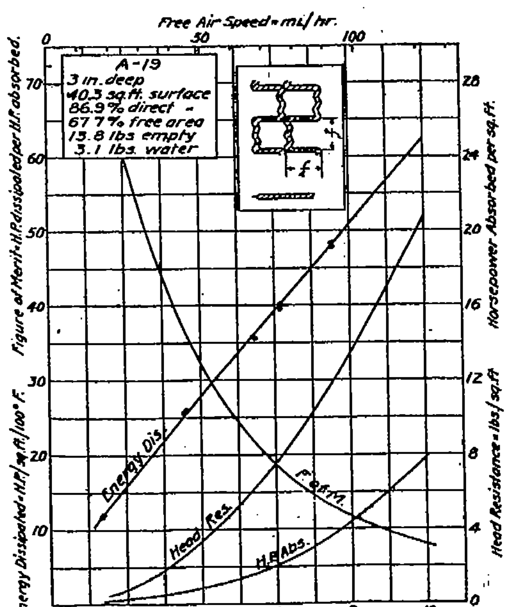
Plot No. 15



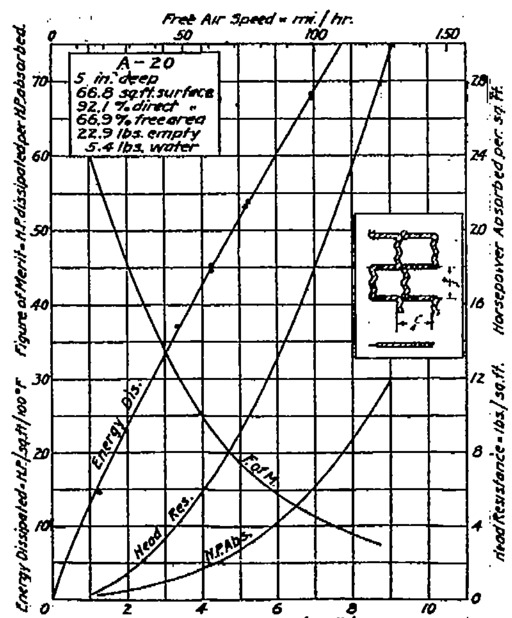
Plot No. 16



Plot No. 17

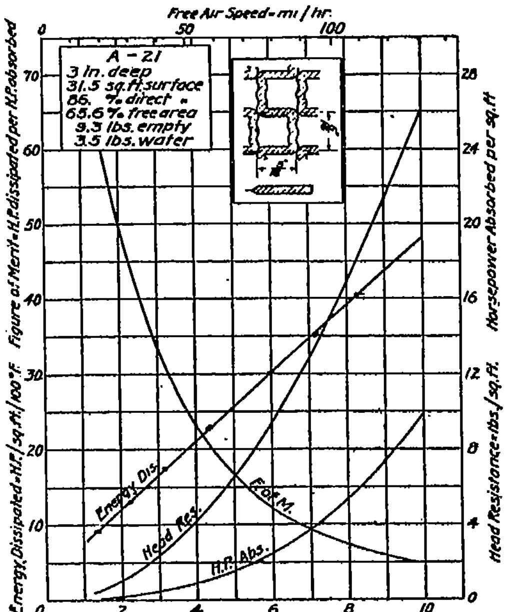


Plot No. 18

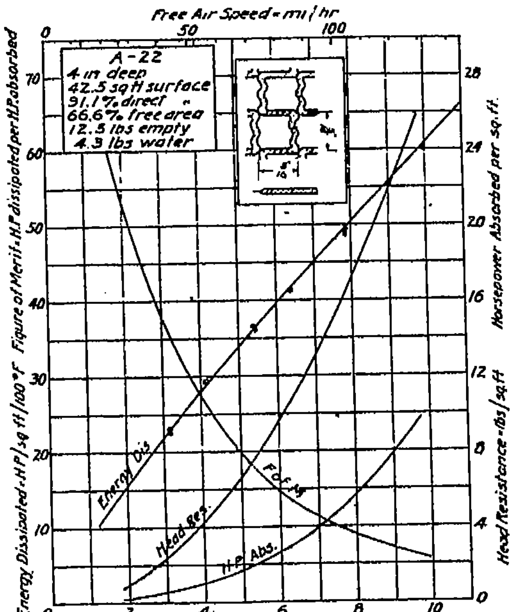


Plot No. 19

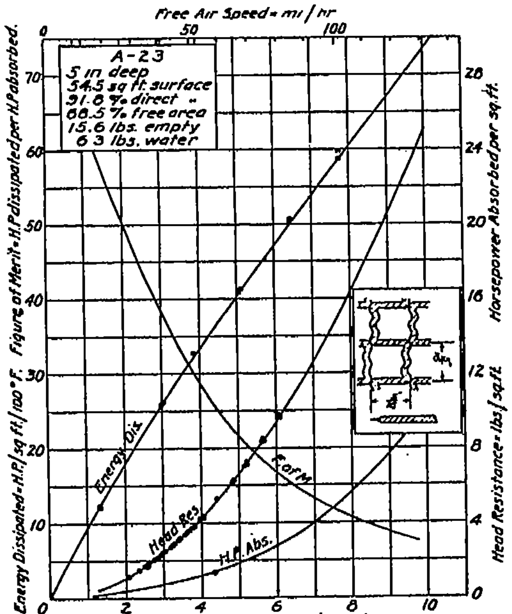
146588—20——3



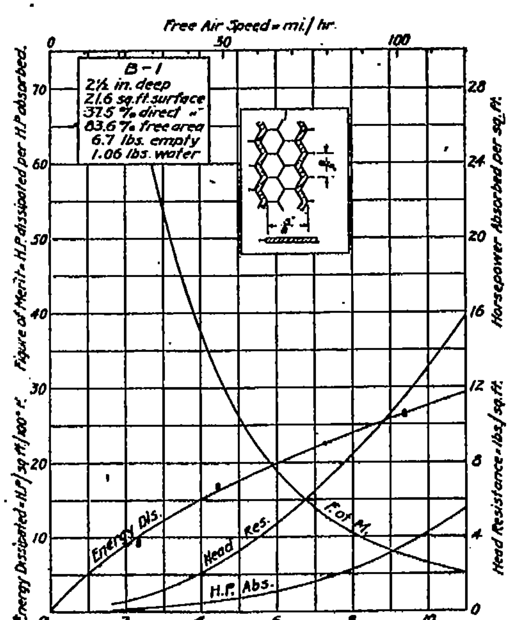
Plot No. 20 Mass Flow of Air = lbs./sq.ft./sec.



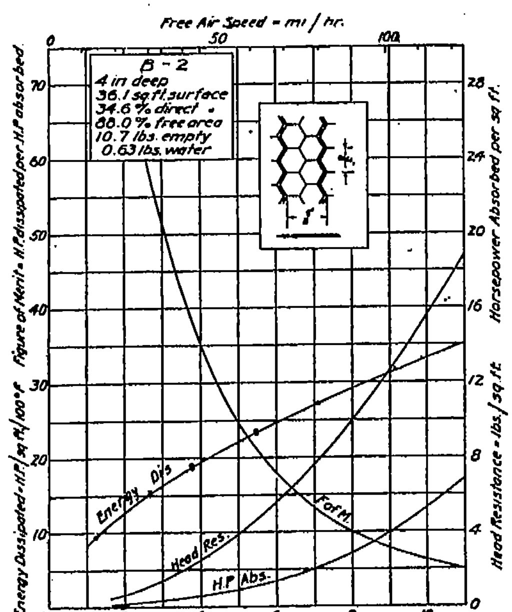
Plot No. 21 Mass Flow of Air = lbs./sq.ft./sec.



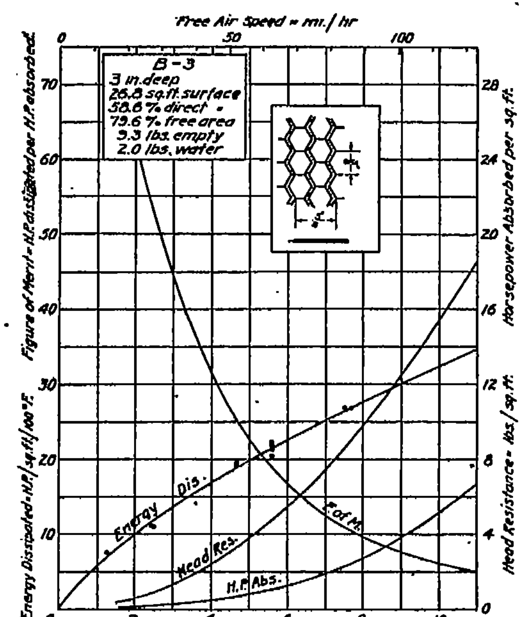
Plot No 22 Mass Flow of Air = lbs./sq.ft./sec.



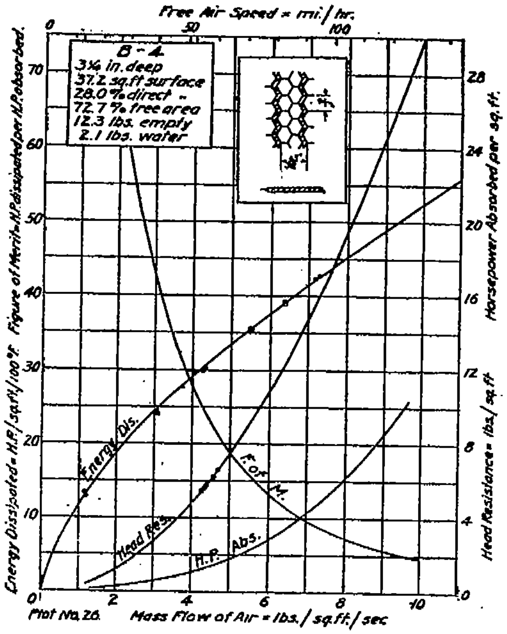
Plot No. 23 Mass Flow of Air = lbs./sq.ft./sec

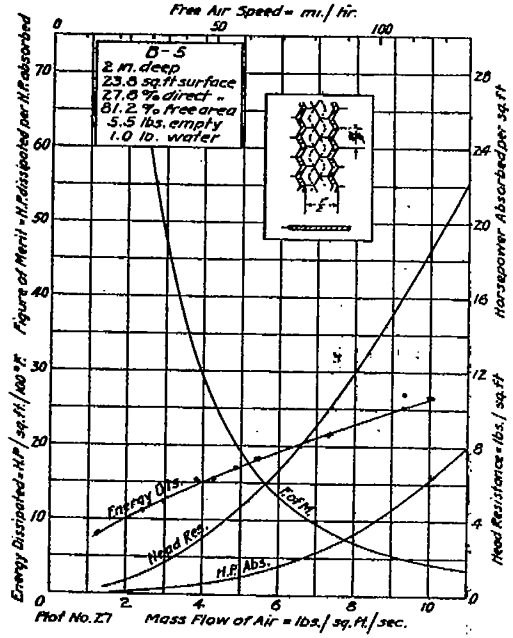


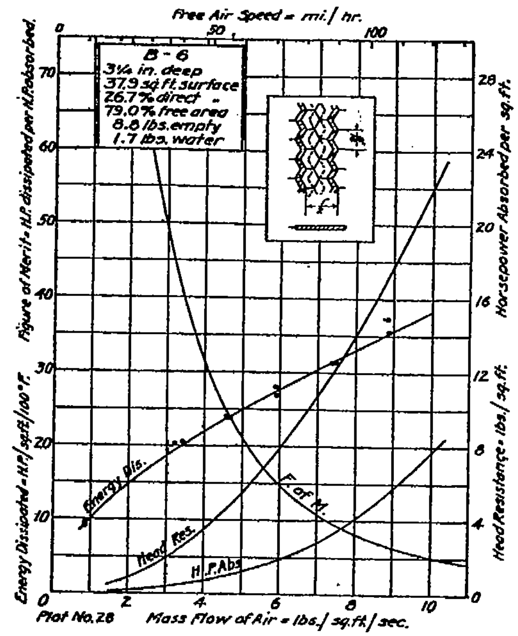
Plot No. 24 Mass Flow of Air = lbs./sq.ft./sec

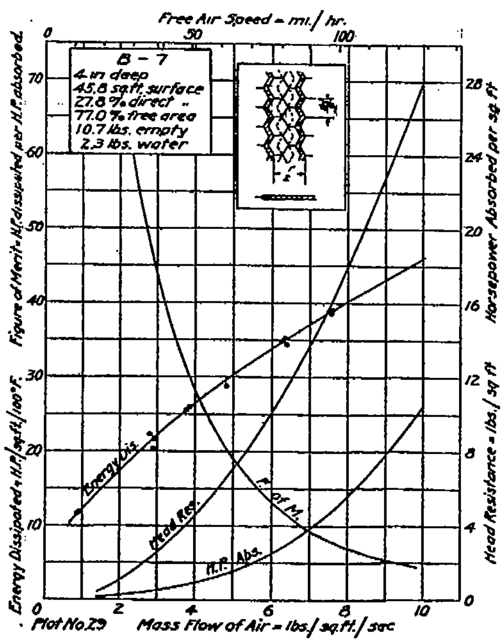


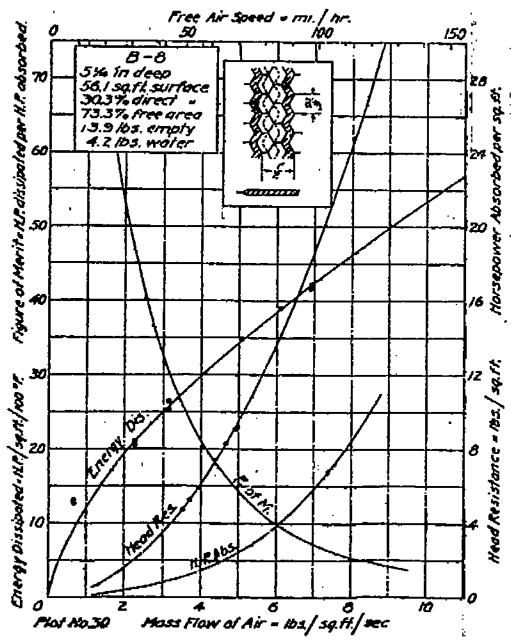
Plot No. 25. Mass Flow of Air = lbs./sq.ft./sec.

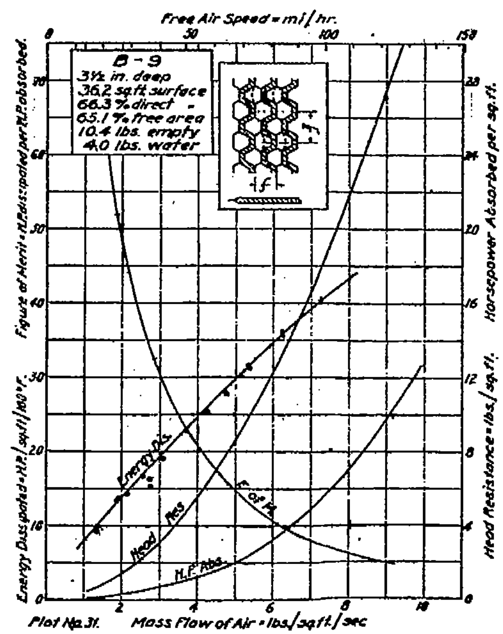

Free Air Speed = mi./hr.
B-4
3¼ in. deep
37.2 sq.ft. surface
28.0 % direct "
72.7 % free area
12.3 lbs. empty
2.1 lbs. water
Energy Dis.
Head Res.
H.P. Abs.
F. of M.
Energy Dissipated = H.P./sq.ft./100° F. Figure of Merit = H.P. dissipated per H.P. absorbed.
Horsepower Absorbed per sq. ft.
Head Resistance = lbs./sq.ft.
Plot No. 26. Mass Flow of Air = lbs./sq.ft./sec

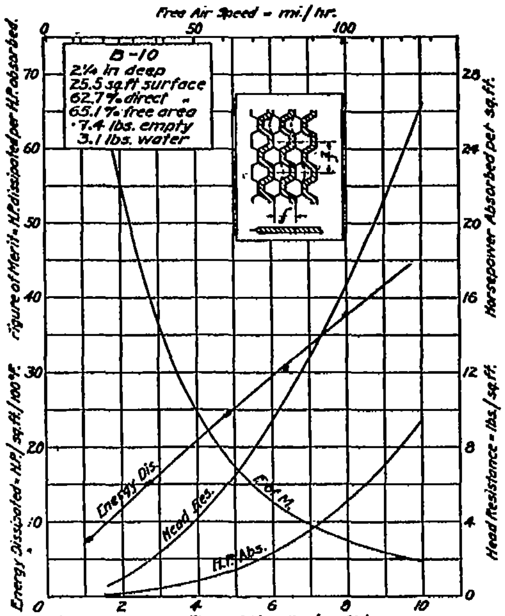

Free Air Speed = mi./hr.
B-5
2 in. deep
23.8 sq.ft. surface
27.8 % direct "
81.2 % free area
5.5 lbs. empty
1.0 lb. water
Energy Dis.
Head Res.
H.P. Abs.
F. of M.
Energy Dissipated = H.P./sq.ft./100° F. Figure of Merit = H.P. dissipated per H.P. absorbed
Horsepower Absorbed per sq. ft.
Head Resistance = lbs./sq.ft.
Plot No. 27 Mass Flow of Air = lbs./sq.ft./sec.


Free Air Speed = mi./hr.
B-6
3¼ in. deep
37.9 sq.ft. surface
26.7 % direct "
79.0 % free area
8.8 lbs. empty
1.7 lbs. water
Energy Dis.
Head Res.
H.P. Abs.
F. of M.
Energy Dissipated = H.P./sq.ft./100° F. Figure of Merit = H.P. dissipated per H.P. absorbed.
Horsepower Absorbed per sq. ft.
Head Resistance = lbs./sq.ft.
Plot No. 28 Mass Flow of Air = lbs./sq.ft./sec.

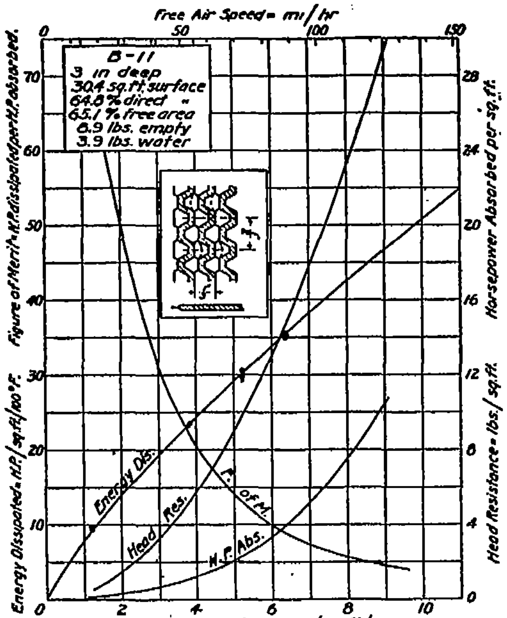

Free Air Speed = mi./hr.
B-7
4 in. deep
45.8 sq.ft. surface
27.8 % direct "
77.0 % free area
10.7 lbs. empty
2.3 lbs. water
Energy Dis.
Head Res.
H.P. Abs.
F. of M.
Energy Dissipated = H.P./sq.ft./100° F. Figure of Merit = H.P. dissipated per H.P. absorbed.
Horsepower Absorbed per sq. ft.
Head Resistance = lbs./sq.ft.
Plot No. 29 Mass Flow of Air = lbs./sq.ft./sec


Free Air Speed = mi./hr.
B-8
5¼ in. deep
56.1 sq.ft. surface
30.3 % direct "
73.3 % free area
13.9 lbs. empty
4.2 lbs. water
Energy Dis.
Head Res.
H.P. Abs.
F. of M.
Energy Dissipated = H.P./sq.ft./100° F. Figure of Merit = H.P. dissipated per H.P. absorbed.
Horsepower Absorbed per sq. ft.
Head Resistance = lbs./sq.ft.
Plot No. 30 Mass Flow of Air = lbs./sq.ft./sec

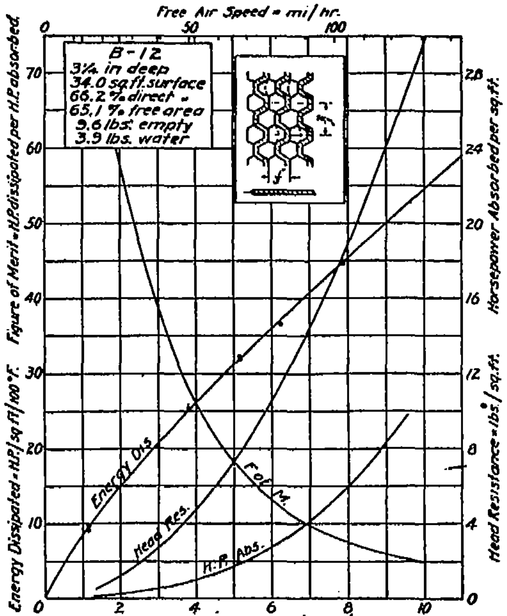

Free Air Speed = mi./hr.
B-9
3½ in. deep
36.2 sq.ft. surface
66.3 % direct "
65.1 % free area
10.4 lbs. empty
4.0 lbs. water
Energy Dis.
Head Res.
H.P. Abs.
F. of M.
Energy Dissipated = H.P./sq.ft./100° F. Figure of Merit = H.P. dissipated per H.P. absorbed.
Horsepower Absorbed per sq. ft.
Head Resistance = lbs./sq.ft.
Plot No. 31. Mass Flow of Air = lbs./sq.ft./sec



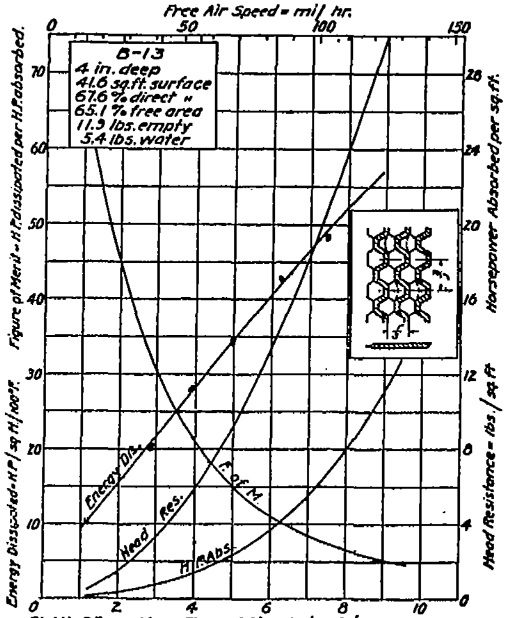
Plot No. 32



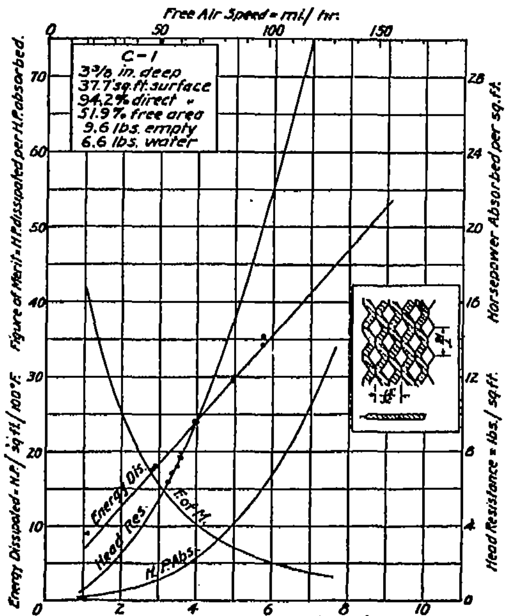
Plot No. 33



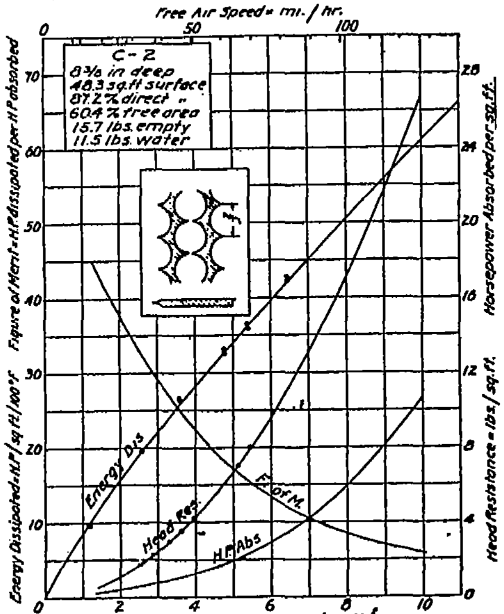
Plot No. 34



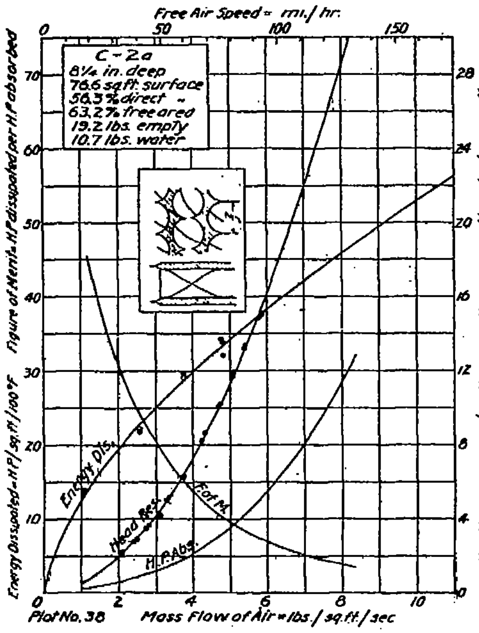
Plot No. 35

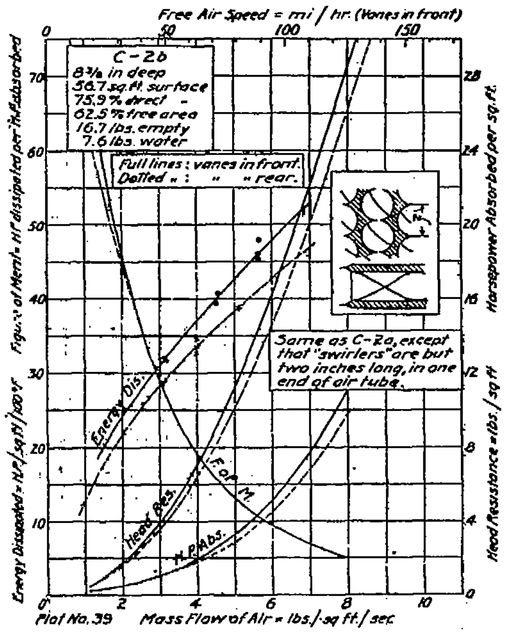


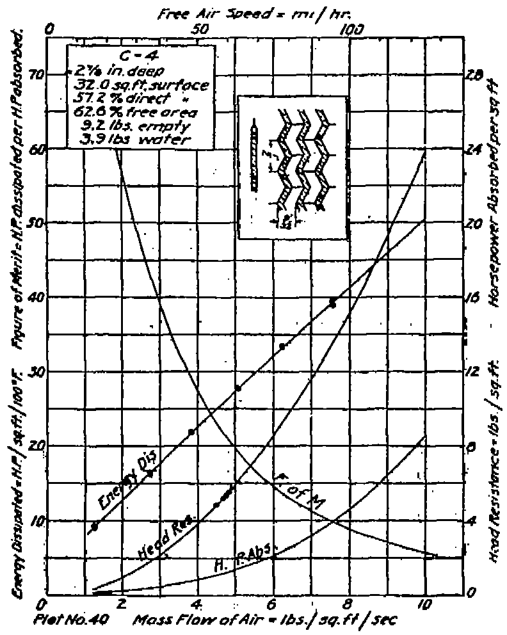
Plot No. 36

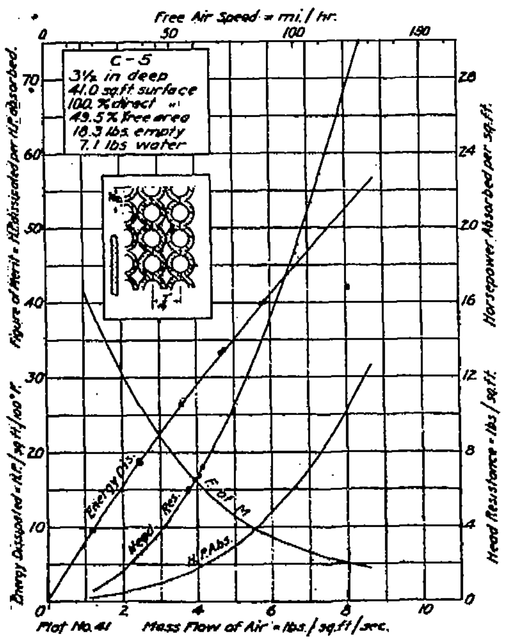


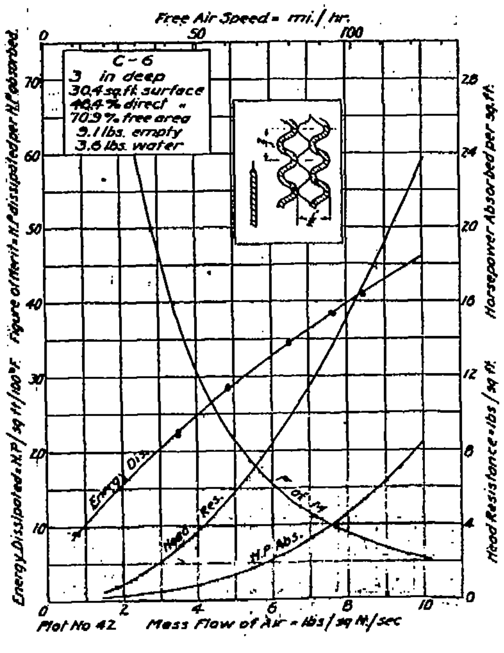
Plot No. 37

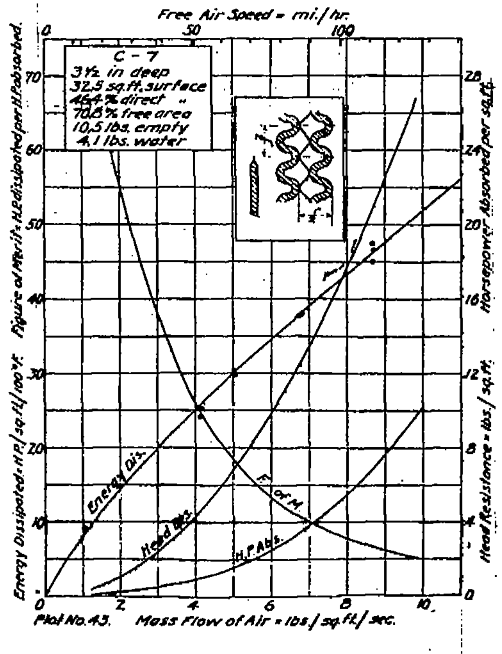

Free Air Speed = mi./hr.
C-2a
8¼ in. deep
76.6 sq.ft. surface
56.3% direct "
63.2% free area
19.2 lbs. empty
10.7 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 38
Mass Flow of Air = lbs./sq.ft./sec.

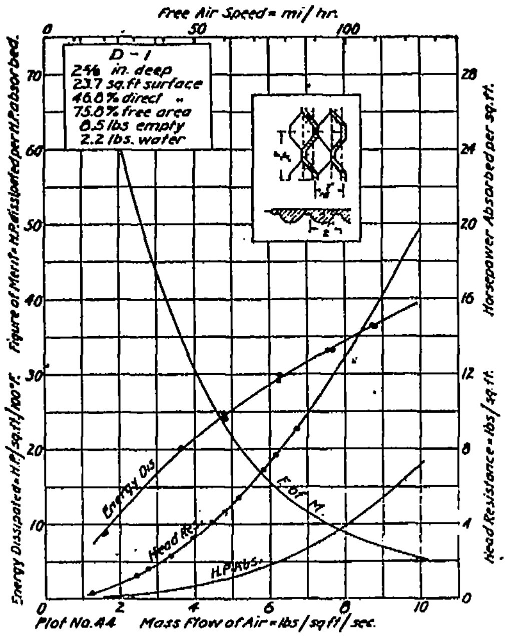

Free Air Speed = mi/hr. (Vanes in front)
C-2b
8¼ in deep
56.7 sq.ft. surface
75.9% direct "
62.5% free area
16.7 lbs. empty
7.6 lbs. water
Full lines: vanes in front.
Dotted " : " " rear.
Same as C-2a, except that "swirlers" are but two inches long, in one end of air tube.
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 39
Mass Flow of Air = lbs./sq.ft./sec.

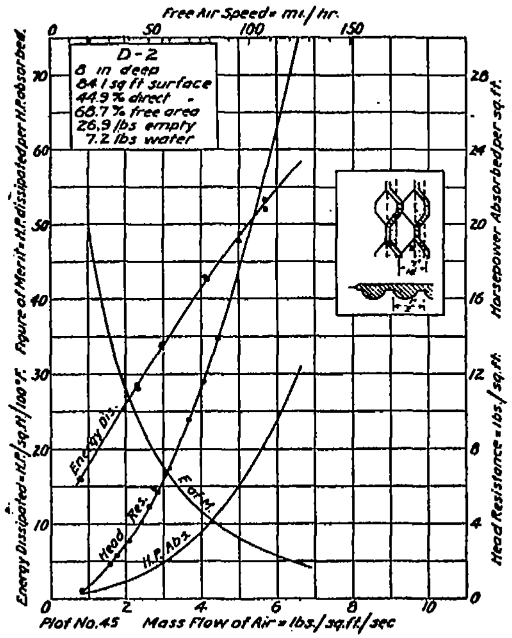

Free Air Speed = mi/hr.
C-4
2⅞ in. deep
32.0 sq.ft. surface
57.2% direct "
62.6% free area
9.2 lbs. empty
3.9 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 40
Mass Flow of Air = lbs./sq.ft./sec.

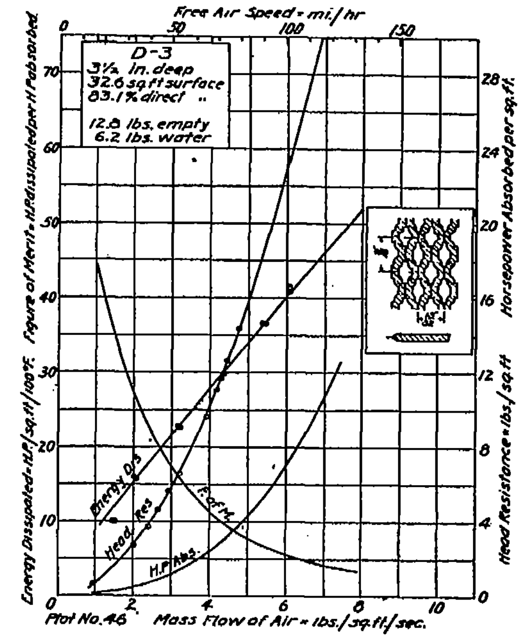

Free Air Speed = mi./hr.
C-5
3½ in deep
41.0 sq.ft. surface
100.% direct "
49.5% free area
18.3 lbs. empty
7.1 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 41
Mass Flow of Air = lbs./sq.ft./sec.

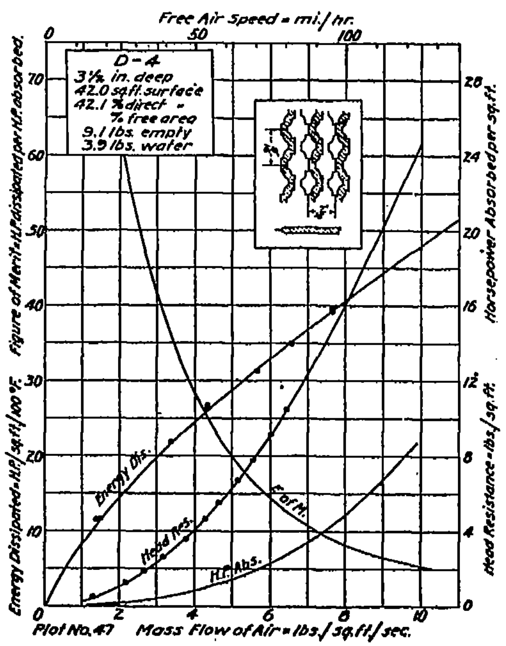

Free Air Speed = mi./hr.
C-6
3 in deep
30.4 sq.ft. surface
46.4% direct "
70.9% free area
9.1 lbs. empty
3.6 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 42
Mass Flow of Air = lbs./sq.ft./sec

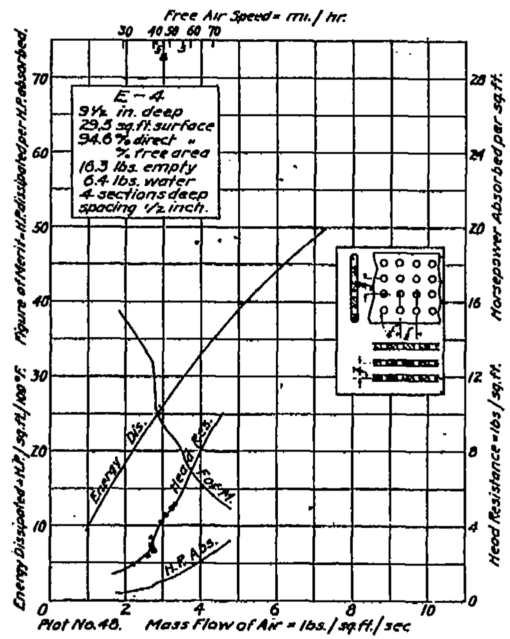

Free Air Speed = mi./hr.
C-7
3½ in deep
32.5 sq.ft. surface
46.4% direct "
70.8% free area
10.5 lbs. empty
4.1 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 43.
Mass Flow of Air = lbs./sq.ft./sec.

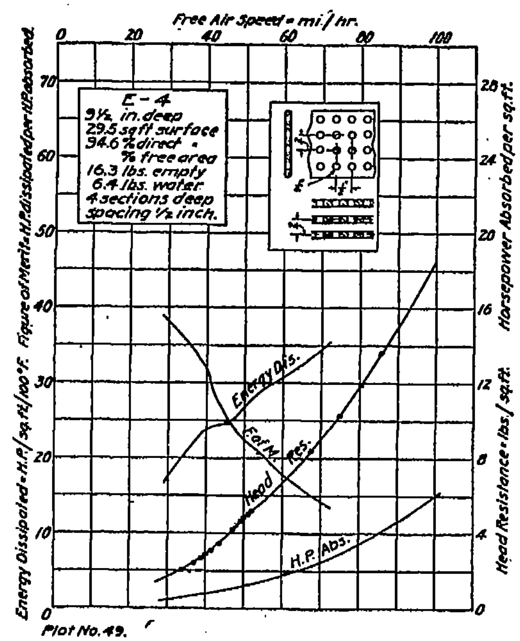

Free Air Speed = mi./hr.
D-1
2⅝ in. deep
23.7 sq.ft surface
46.8% direct "
75.8% free area
6.5 lbs empty
2.2 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 44 Mass Flow of Air = lbs./sq.ft./sec.

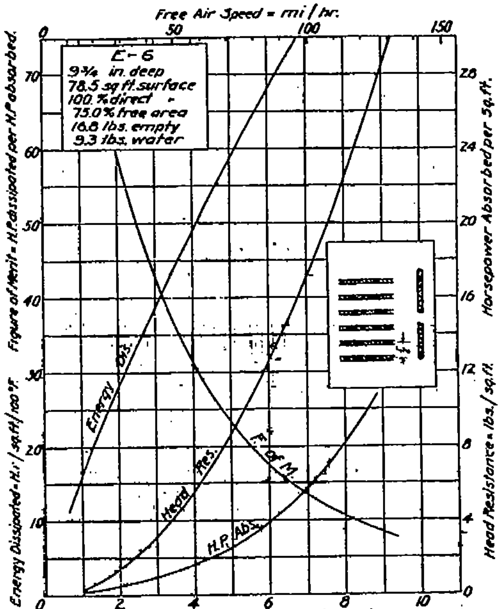

Free Air Speed = mi./hr.
D-2
8 in. deep
84.1 sq.ft surface
44.9% direct "
68.7% free area
26.9 lbs empty
7.2 lbs water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 45 Mass Flow of Air = lbs./sq.ft./sec


Free Air Speed = mi./hr
D-3
3⅛ in. deep
32.6 sq.ft surface
83.1% direct "
12.8 lbs. empty
6.2 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft
Plot No. 46 Mass Flow of Air = lbs./sq.ft./sec.

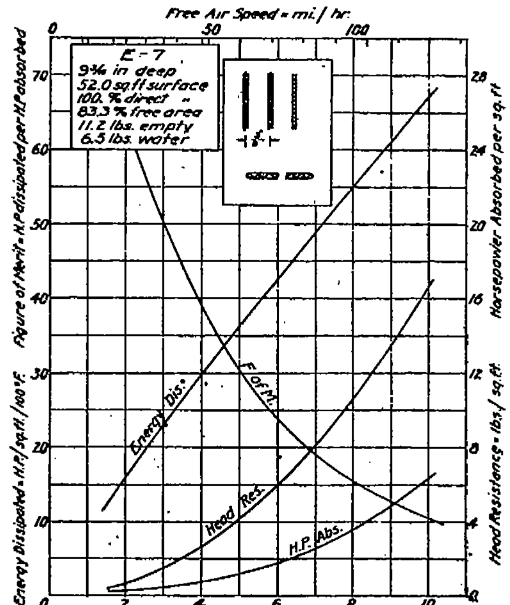

Free Air Speed = mi./hr.
D-4
3⅛ in. deep
42.0 sq.ft. surface
42.1 % direct "
% free area
9.1 lbs. empty
3.9 lbs. water
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 47 Mass Flow of Air = lbs./sq.ft./sec.


Free Air Speed = mi./hr.
E-4
9½ in. deep
29.5 sq.ft. surface
94.6% direct "
% free area
16.3 lbs. empty
6.4 lbs. water
4 sections deep
spacing ½ inch.
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed.
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 48. Mass Flow of Air = lbs./sq.ft./sec

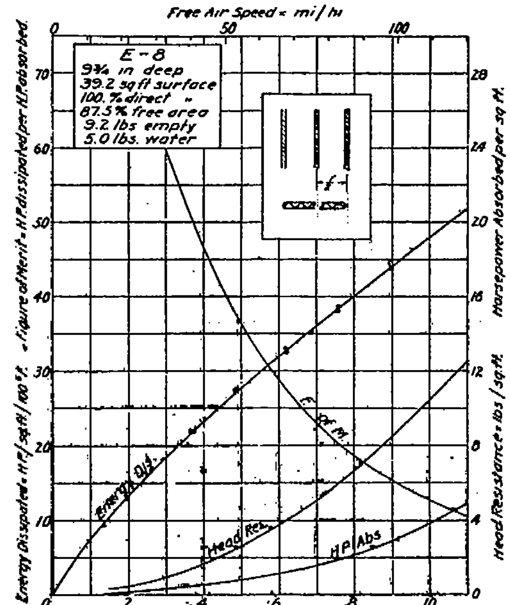

Free Air Speed = mi./hr.
E-4
9½ in. deep
29.5 sq.ft. surface
94.6% direct "
% free area
16.3 lbs. empty
6.4 lbs. water
4 sections deep
spacing ½ inch.
Energy Dis.
Head Res.
F. of M.
H.P. Abs.
Figure of Merit = H.P. dissipated per H.P. absorbed
Energy Dissipated = H.P./sq.ft./100°F.
Horsepower Absorbed per sq.ft.
Head Resistance = lbs./sq.ft.
Plot No. 49.



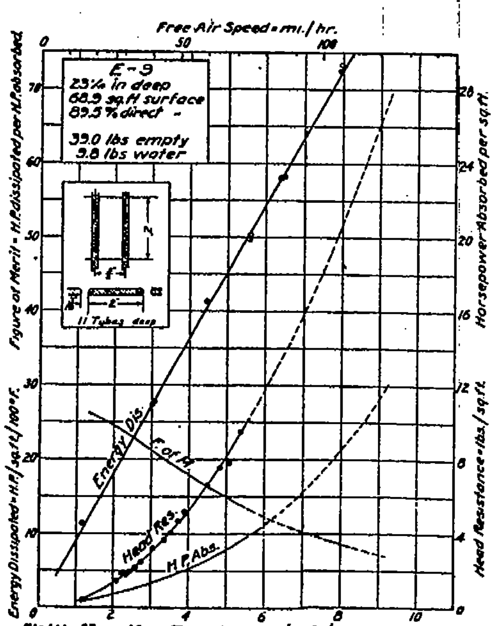
Plot No. 50.



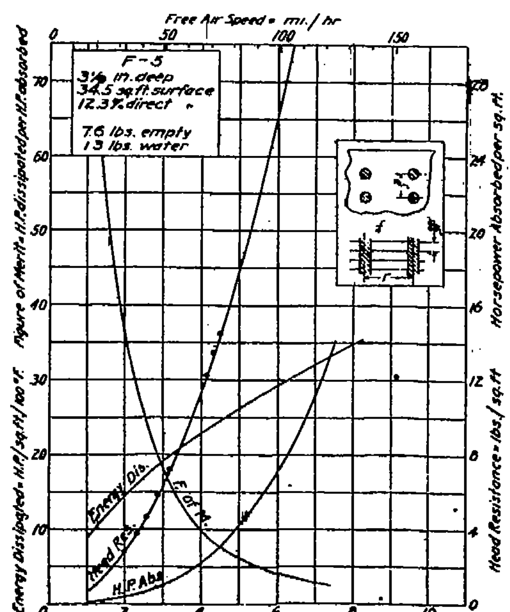
Plot No. 51



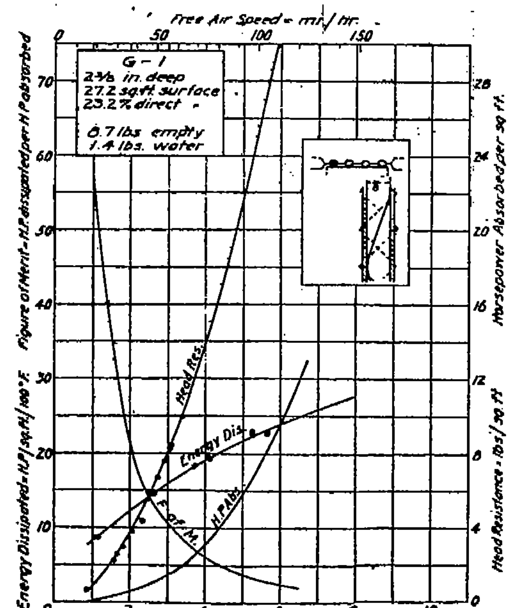
Plot No. 52



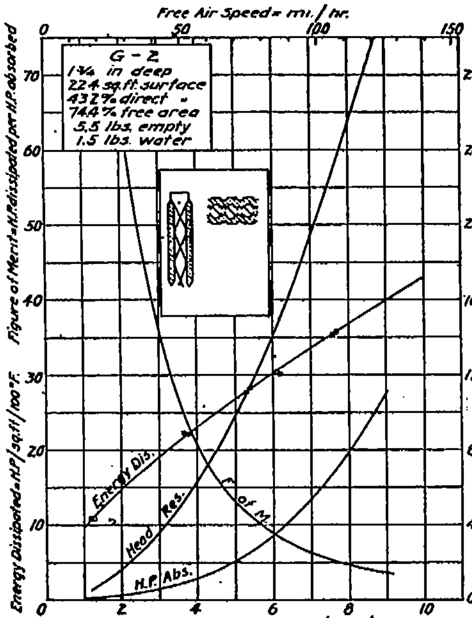
Plot No. 53.



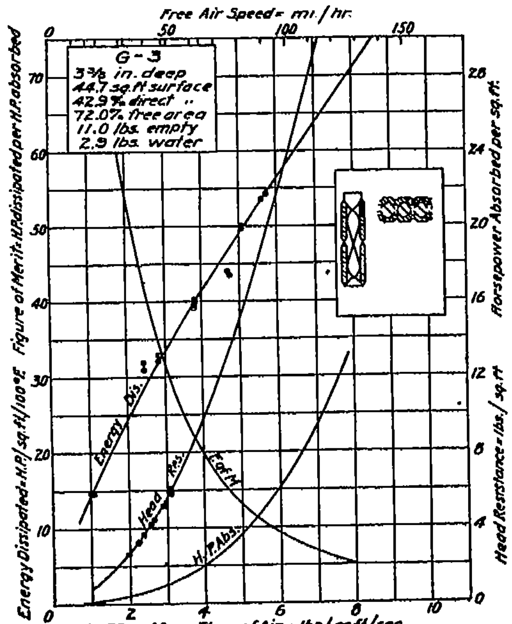
Plot No. 54



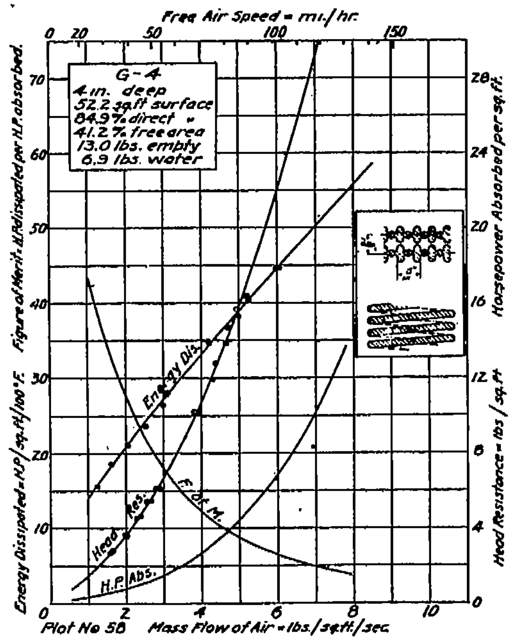
Plot No. 55.



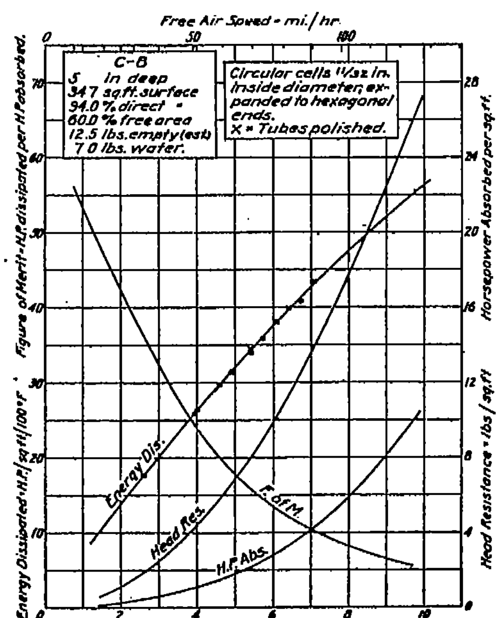
Plot No 56



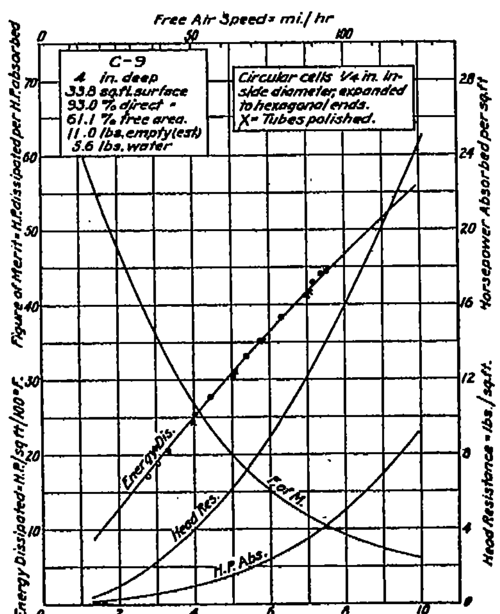
Plot No. 57.



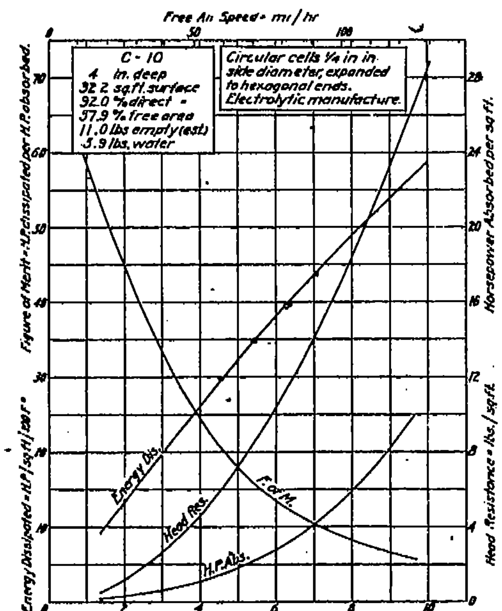
Plot No 58



Plot No. 59.



Plot No. 60



Plot No 61.

REPORT No. 63.

PART II.

WATER FLOW THROUGH RADIATOR CORES.[1]

By W. S. JAMES.

PURPOSE OF TESTS.

The tests were made to determine the pressure necessary to produce water flows up to 50 gallons per minute through an 8-inch square section of radiator core.

RADIATOR CORES TESTED.

The radiator cores tested were made up by the manufacturers in approximately 8-inch square sections and fitted with rectangular water boxes, as shown in figures 1 to 12. The makes and core depths of the sections tested were as follows:

(1) Ajax Auto and Aero Sheet Metal Co., 1/4-inch square tubes, 4 inches deep.
(2) G. & O. Manufacturing Co., 1/4-inch rhombic tubes, 3 3/8 inches deep.
(3) The Harrison Radiator Corporation, 5/16-inch hexagonal tubes, 4 inches deep.
(4) The Livingston Radiator & Manufacturing Co., 1/4-inch square tubes, 4 inches deep.
(5) The Livingston Radiator & Manufacturing Co., 5/16-inch square tubes, 4 inches deep.
(6) The Rome-Turney Radiator Co., 1/4-inch square tubes, 3 3/8 inches deep.
(7) The McCord Manufacturing Co., 5/16-inch elliptical tubes, 3 1/2 inches deep.
(8) The McCord Manufacturing Co., fin and tube, 3 5/8 inches deep.
(9) The Modine Manufacturing Co., (Spirex core) 11/16-inch square tube with spirals, 3 1/2 inches deep.
(10) The Sparks-Withington Co., 3/8-inch elliptical tube, 3 1/2 inches deep.
(11) The Hooven Sales Corporation, (Spery core) 5/8-inch elliptical tube, 2 5/8 inches deep.
(12) The Western Mechanical Works, (Staggered core) 5/16-inch staggered square tube, 4 inches deep.

METHOD OF TEST.

The radiator sections were connected in the discharge line of a centrifugal pump and in series with a venturi meter. The discharge from the radiator was connected to the inlet of the pump. A reserve water tank in which a constant head of water was automatically maintained was connected to the suction line of the pump to provide a water reserve and to act as a surge tank. The centrifugal pump was driven by a belt from a direct current shunt motor.

The rate of water flow was measured by a Venturi meter with a 1-inch diameter inlet and a 1/2-inch diameter throat. The Venturi pressure difference was observed on a mercury gauge. The constant of the Venturi tube and gauge was determined by careful calibration. A constant pressure water supply from a pressure regulating valve was used as a source of water and the discharge was measured by means of a large weighing tank of about 100 cubic feet capacity.

The pressure drop in the water was measured by means of piezometer connections soldered on the radiator water boxes. These piezometer connections were made by soldering square copper tubes to the outside of the water boxes, then drilling from the outside one millimeter holes, spaced one inch apart, through both walls of the square copper tube and the water box top.

Holes were then bored in the water box ends and a scraping tool inserted in the water box to scrape off the burr on the holes inside the water boxes. A V-shaped strip of galvanized iron was then inserted in the water box to protect the holes from the effects of the impact of the high velocity water streams impinging on the piezometer tube holes. The holes in the

[1] This Report was confidentially circulated during the war as Bureau of Standards Aeronautic Power Plants Report No. 3.

ends of the water boxes were then soldered up. The pressure difference between the two piezometer tubes was observed either on a long carbon-tetrachloride gauge or on a mercury gauge.

A general view of the set-up is given in figure 13. The pump is shown discharging through a control plug-cock, the Venturi meter tube and the radiator. The pressure drop and Venturi gauges can also be seen.

METHOD OF TAKING OBSERVATIONS.

In taking the observations the water level in the surge tank was adjusted to a constant height, then the pump was started and the air removed from the system by means of the air relief connections at the high points in the pressure connections. The rate of water flow was then adjusted to the desired value by means of the plug cock at the discharge of the pump. A small electric desk fan placed so as to force air through the radiator and thus keep the water cool was started and when the flow had reached a steady state six sets of readings were taken, three sets by each observer. The readings taken were (1) the reading of the Venturi meter gauge, (2) the reading of the pressure drop gauge, and (3) the temperature of the water in the system. When these observations were complete the rate of flow was adjusted to the next higher value and the readings repeated.

Table of water tube characteristics.

Radiator.	Area of each water tube.	Width of each water tube.	Thickness of each water tube.	Mean hydraulic radius of each water tube.	Length of each water tube parallel to direction of water flow.
	Square inch.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
Ajax	0.125	3.65	0.034	0.0170	7.68
G. & O.	.226	2.91	.078	.0378	9.67
Harrison	.204	3.50	.058	.0287	9.02
Livingston ¼ inch	.0946	3.57	.027	.0138	15.97
Livingston $\frac{5}{16}$ inch	.132	3.57	.037	.0183	15.58
Rome-Turney	.156	3.00	.052	.0255	8.00
McCord fin and tube	.0433	....	.0235	[a].0587	8.00
McCord elliptical	.244	3.02	.081	.0393	9.77
Spirex	.154	2.99	.052	.0254	8.75
Sparks-Withington	.320	3.07	.104	.0532	11.03
Spery	.178	2.29	.075	.0365	8.03
Staggered	.422	3.20	.132	.0634	7.88

[a] Diameter.

METHOD OF WORKING UP RESULTS.

The values of the rates of flow were computed in gallons per minute for each of the Venturi gauge readings at each rate of flow and the mean of these six readings taken as the mean rate of flow. The values of the pressure drop in the water were then computed from the six pressure drop gauge readings and the mean of these six readings was taken as the pressure drop corresponding to the measured rate of flow.

In this manner five points were obtained on the rate of flow-pressure drop curve for each radiator. The logarithms of the rates of flow were then plotted against the logarithms of the pressure drops and the observed points were found to lie on a straight line. Then as it was found that it was impossible to obtain greater flows than 25 gallons per minute with the set-up without bulging the water boxes of the radiators, the straight lines on the logarithmic plots were continued on to 50 gallons per minute. The anti-logarithms of the pressure drops were then found for points on the logarithmic curves corresponding to 30, 35, 40, 45, 50 and 55 gallons per minute. Plots 14 to 25 were then made by using the observed values of the pressure drop from 0 to 25 gallons per minute and the extrapolated values of the pressure drop from 25 to 55 gallons per minute found as indicated.

Because of the fact that the logarithmic plots gave straight lines it is evident that the observed results may be expressed by an empirical equation of the form

$$P = CQ^n$$

Where P is the pressure drop in feet of water, Q is the rate of flow in gallons per minute. C and n are constants. Values of n were found from the slopes of the logarithmic lines and are given on the plots for each radiator.

METHOD DEVISED FOR THE APPLICATION OF THE RESULTS OF THE ACCOMPANYING TESTS ON THE PRESSURE NECESSARY TO MAINTAIN WATER FLOW THROUGH RADIATOR CORES.

The following method of approximating the pressures necessary to maintain water flows through radiator cores has been devised in order to make immediate use of the data given in this report in estimating the order of magnitude of the pressure necessary to maintain water flows through radiator cores of dimensions (i. e., core lengths, widths and depths) differing from those used in the experiments described.

Extreme accuracy can not be expected of the approximation given, the error being between 10 and 20 per cent. The terms width, length and depth of the core as used in this report are defined as follows:

Core width is the linear dimension of the core, perpendicular to both the direction of water flow and the direction of air flow.

Core length is the linear dimension of the core, parallel to the direction of water flow.

Core depth is the linear dimension of the core, parallel to the direction of air flow.

METHOD OF USING PLOTS.

The method used is based upon the pressure necessary to maintain a given rate of flow through single water tubes 1 foot long and of varying depths of core (i. e., 3 inches, 3.5 inches, 4 inches, 4.5 inches, 5 inches, and 5.5 inches).

If all the water tubes in the radiator core carry equal amounts of water, the amount of water carried by each tube of any radiator section can be computed provided the following data are known: (1) The volume of water to be forced through the total width of core per minute, (2) the total width of radiator core and (3) the number of water tubes per foot of width. The first two factors (1) and (2) are dependent on the design of the radiator in question, the latter (3) is given on plots 26 to 37 for the cores tested.

When the amount of water to be carried by each tube has been determined the pressure necessary to maintain the required rate of flow can be read from the plots which gives the pressures necessary to maintain various rates of flow through a single water tube one foot in length of the make of radiator core indicated. On these plots curves are drawn for even one-half inch depths of core from 3 to 5.5 inches. The pressure corresponding to the flow desired may be read from the curve for the core depth to be used or found by estimation between the curves for the core depths given.

The pressure found from the plot is then multiplied by the length of the radiator core in the direction of water flow. The product of the pressure necessary to maintain the desired flow through one foot length of radiator core multiplied by the core length will give the approximate value of the pressure required to maintain the desired rate of water flow.

For example: It is desired to find the pressure necessary to maintain a water flow of 100 gallons per minute through a "Spery" radiator core 32 inches long 16 inches wide and 4 inches deep.

As there are 30 water tubes per foot width of core, there are 40 tubes per 16 inches of width.

The rate of flow through each tube will therefore be $\frac{100}{40} = 2.5$ gallons per tube per minute.

From the plot, a pressure of 10.7 feet of water per foot of tube length is required to maintain a flow of 2.5 gallons per minute per tube.

As the tube length is 2.5 feet, a pressure of $2.5 \times 10.7 = 27$ feet of water will be required to maintain a flow of 100 gallons of water per minute through the "Spery" core 16 inches wide and 32 inches long.

METHOD OF CONSTRUCTING PLOTS.

The following method was adopted in constructing the plots of the pressures necessary to produce given rates of water flow through single tubes 1 foot long with varying depths.

Values of the pressure necessary to maintain rates of flow of 10, 20, 30, 40, and 50 gallons per minute through an 8-inch width of core were read from the plot for each type of radiator tested. These values of the pressure necessary for an 8-inch core were multiplied by 1.5 to reduce them to the value for a core length of 1 foot. The various rates of flow (i. e., 10, 20, 30, 40, and 50 gallons per minute) were then divided by the number of tubes and the corresponding values of the flow in gallons per tube found.

The Chezy formula for water flow was then assumed in the form given below (1) and the effect on the value of $\triangle P$ of changing core depths found for the rates of flow indicated above as follows:

V = Linear water velocity.

$\triangle P$ = Pressure necessary to maintain velocity V.

R = Hydraulic radius of water tube.

$$= \frac{\text{Area of water tube}}{\text{Perimeter of water tube.}}$$

A = Area of water tube.

Q = Rate of water flow.

t = Water tube thickness.

d = Water tube depth.

n & c = constants.

$$V = C\,(R\triangle P)^{\frac{1}{n}} \tag{1}$$

Now $Q = AV$, $A = td$, and $R = \frac{td}{2(t+d)}$.

Substitution of these values in (1) gives,

$$Q = Ctd\left[\frac{\triangle P}{2}\times\frac{td}{t+d}\right]^{\frac{1}{n}}$$

$$\triangle P = \frac{2Q^n}{C^n}\times\frac{t+d}{(td)^{n+1}},$$

so that

$$\frac{\triangle P_1}{\triangle P_2} = \frac{(t_1+d_1)(t_2d_2)^{n+1}}{(t_2+d_2)(t_1d_1)^{n+1}}.$$

Since $t_1 = t_2$, we have

$$\triangle P_1 = \triangle P_2\left(\frac{d_2}{d_1}\right)^{n+1}\left(\frac{t_1+d_1}{t_2+d_2}\right). \tag{2}$$

Equation (2) provides a means of evaluating $\triangle P$ for a core 3 inches, 3.5 inches, 4 inches (etc.) deep when the value of $\triangle P$ for a core "d" inches deep "t" inches thick and the exponent "n" are known.

When the values of $\triangle P$ for various core depths are found in the manner indicated above and are read directly from the curves plotted, the following assumptions have been tacitly made:

(1) That the same quantity of water passes through each water tube in the core.

(2) That the pressure maintaining flow varies directly as the length of the water tube parallel to the direction of water flow, and that the entrance and exit losses are neglected.

(3) That the pressure necessary to produce flow varies inversely as the hydraulic radius and directly as the "nth" power of the linear water velocity. The values of "n" being found by experiment when the hydraulic radius remains constant.

(4) That the water tube thickness remains constant for any given core and has the value given, when the depth of the core and the length of the water path change.

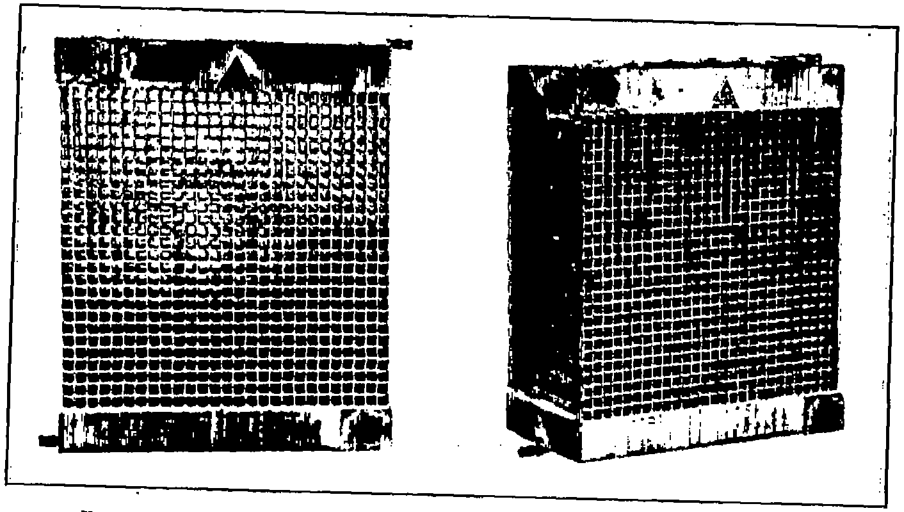


FIGURE 1.—Ajax Auto and Aero Sheet Metal Co. $\frac{1}{4}$-inch square tubes. Core 4 inches deep.

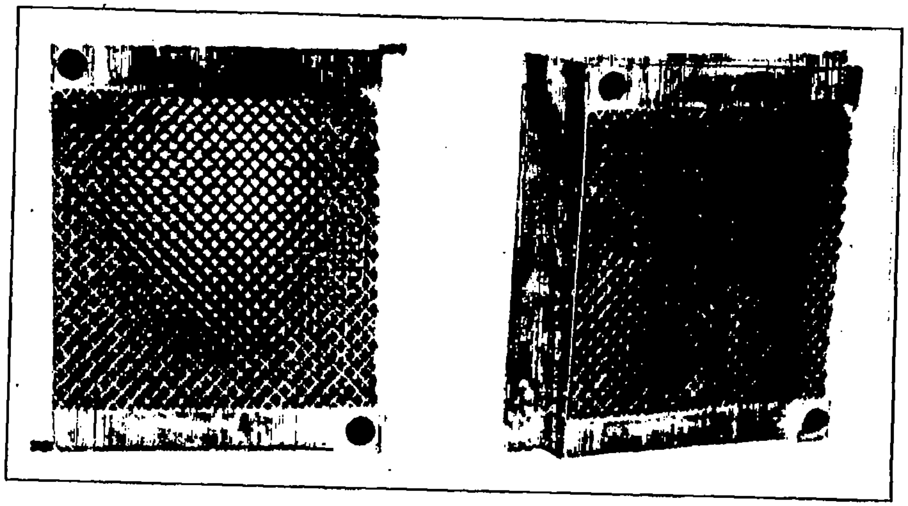


FIGURE 2.—G. & O. Manufacturing Co. $\frac{1}{4}$-inch rhombic tubes. Core $3\frac{3}{4}$ inches deep.

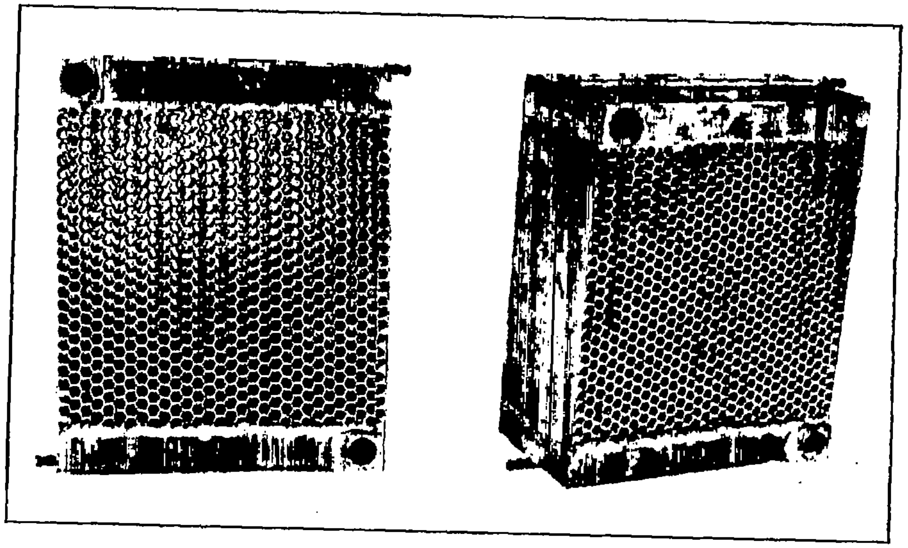


FIGURE 3.—The Harrison Radiator Corporation. $\frac{5}{16}$-inch hexagonal tubes. Core 4 inches deep.

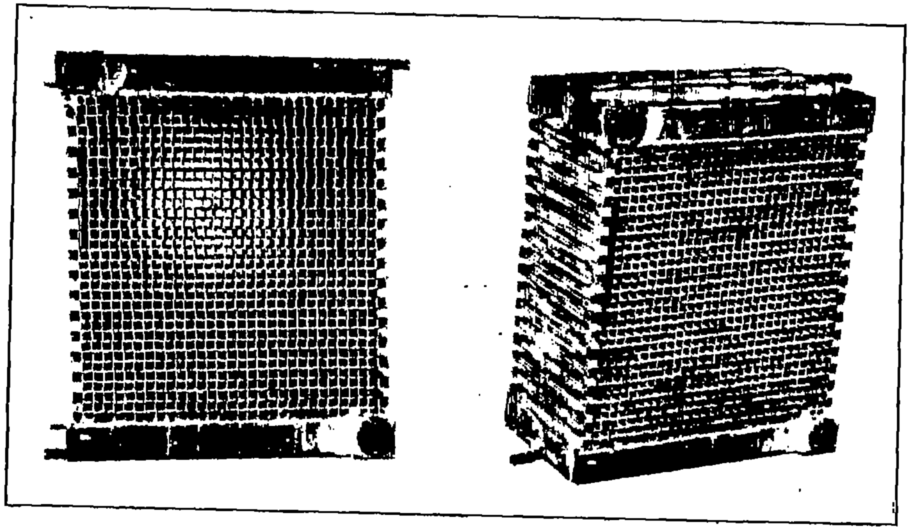


FIGURE 4.—The Livingston Radiator & Manufacturing Co. $\frac{1}{4}$-inch square tube. Core 4 inches deep.

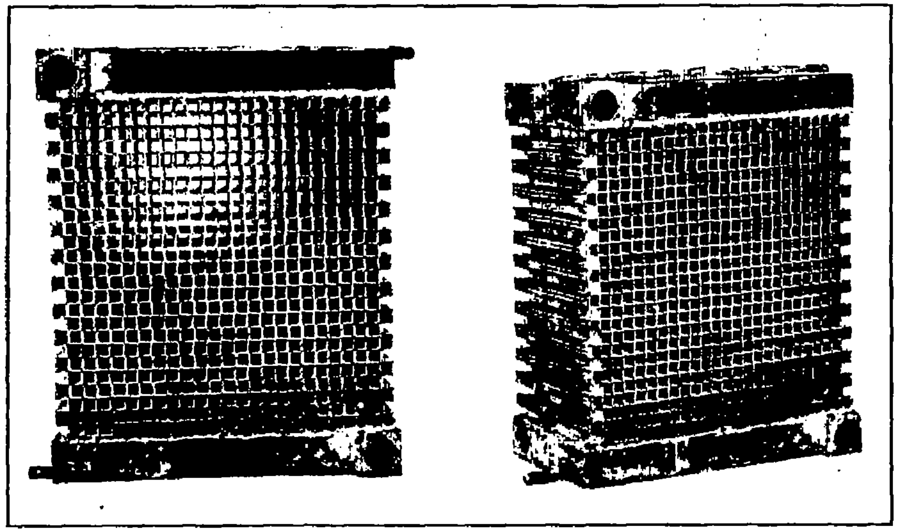


FIGURE 5.—The Livingston Radiator & Manufacturing Co. $\frac{5}{16}$-inch square tubes. Core 4 inches deep.

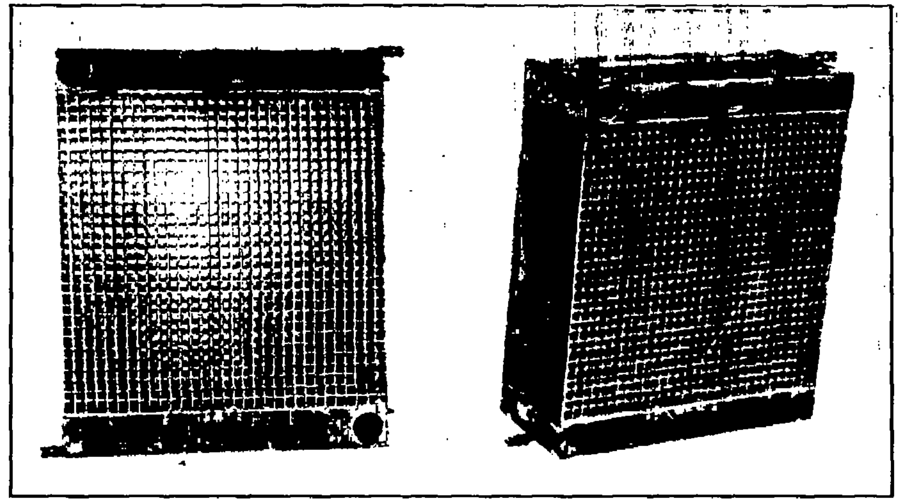


FIGURE 6.—The Rome-Turney Radiator Co. $\frac{1}{4}$-inch square tubes. Core $3\frac{5}{8}$ inches deep.

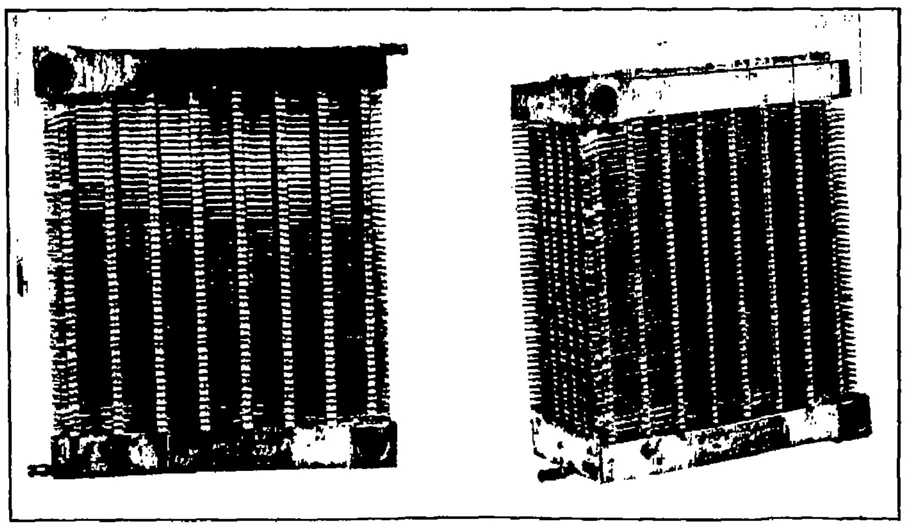


FIGURE 7.—The McCord Manufacturing Co. Fin and tube. Core $3\frac{5}{8}$ inches deep.

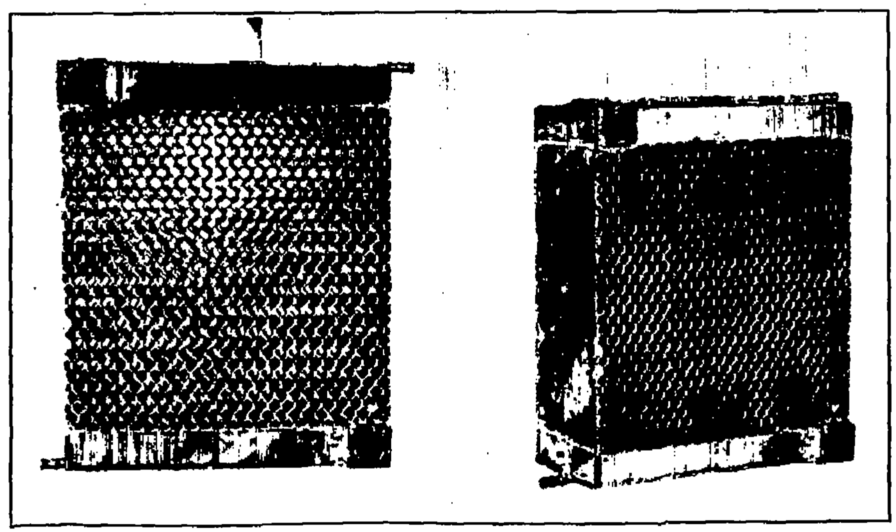


FIGURE 8.—The McCord Manufacturing Co. $\frac{5}{16}$-inch elliptical tubes. Core $3\frac{1}{2}$ inches deep.

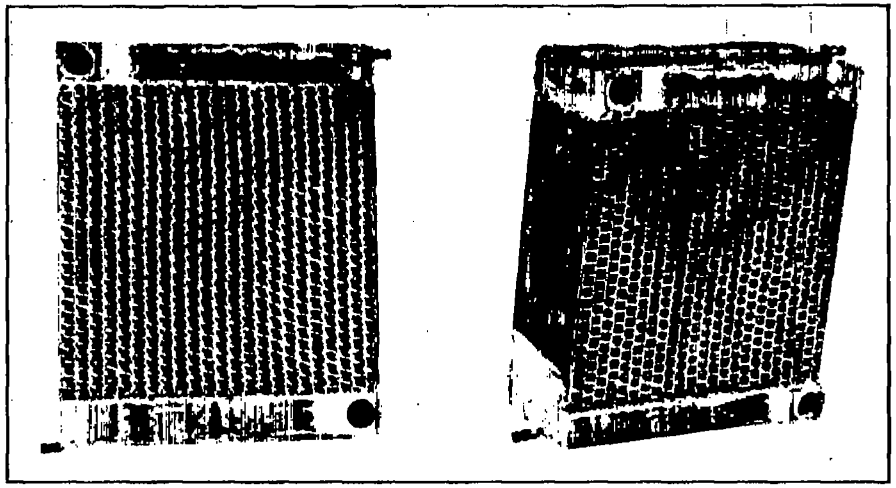


FIGURE 9.—The Modine Manufacturing Co. $\frac{11}{16}$-inch square tube with spirals. Core $3\frac{1}{4}$ inches deep.

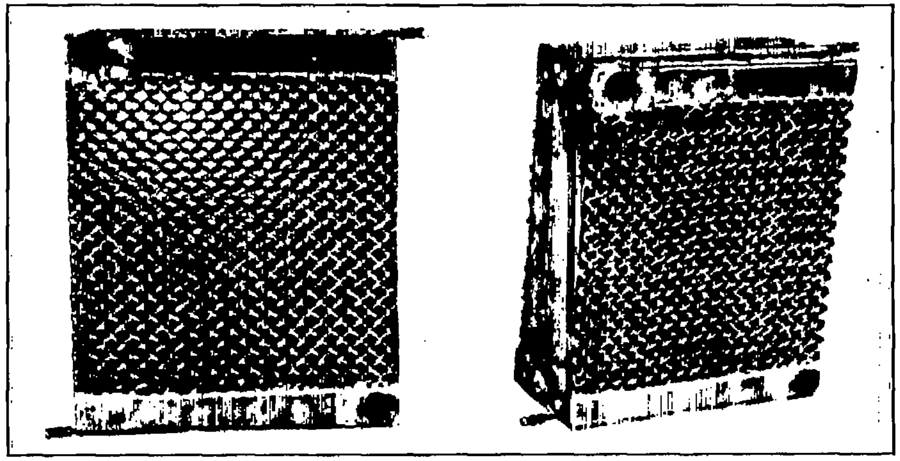


FIGURE 10.—The Sparks-Withington Co. $\frac{3}{8}$-inch elliptical tube. Core $3\frac{1}{4}$ inches deep.

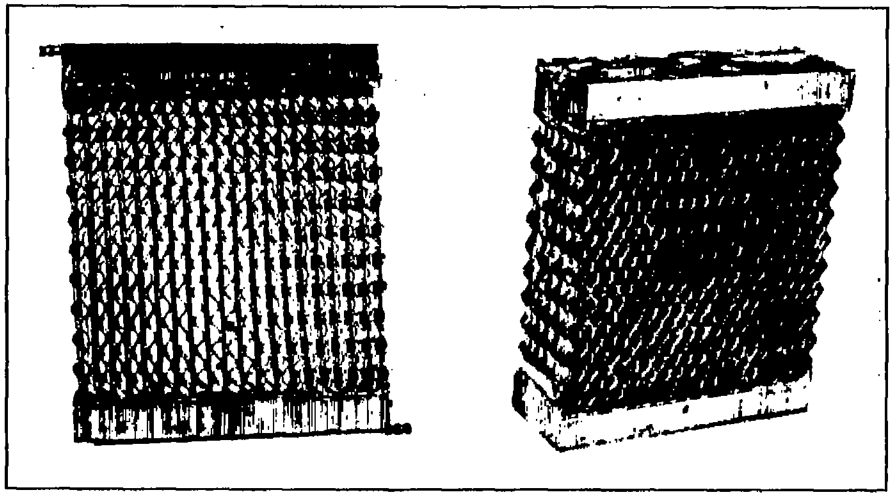


FIGURE 11.—The Hooven Sales Corporation. $\frac{3}{8}$-inch elliptical tube. Core $2\frac{5}{8}$ inches deep.

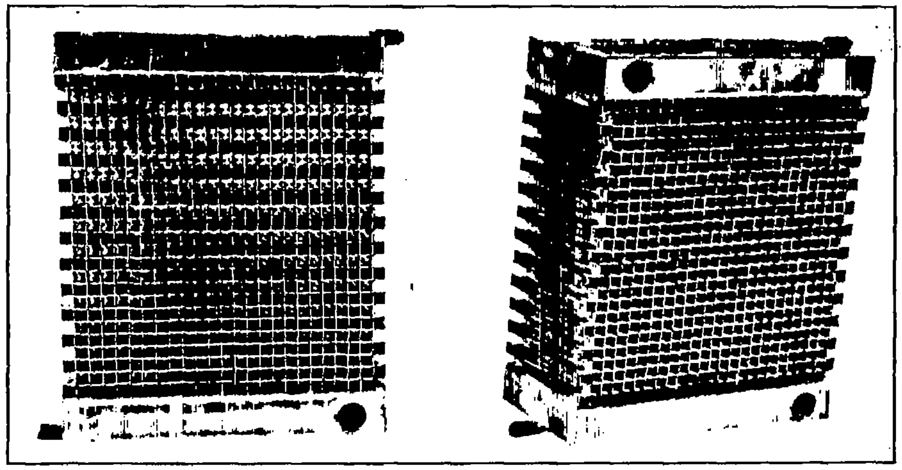


FIGURE 12.—The Western Mechanical Works. $\frac{7}{16}$-inch staggered square tube. Core 4 inches deep.

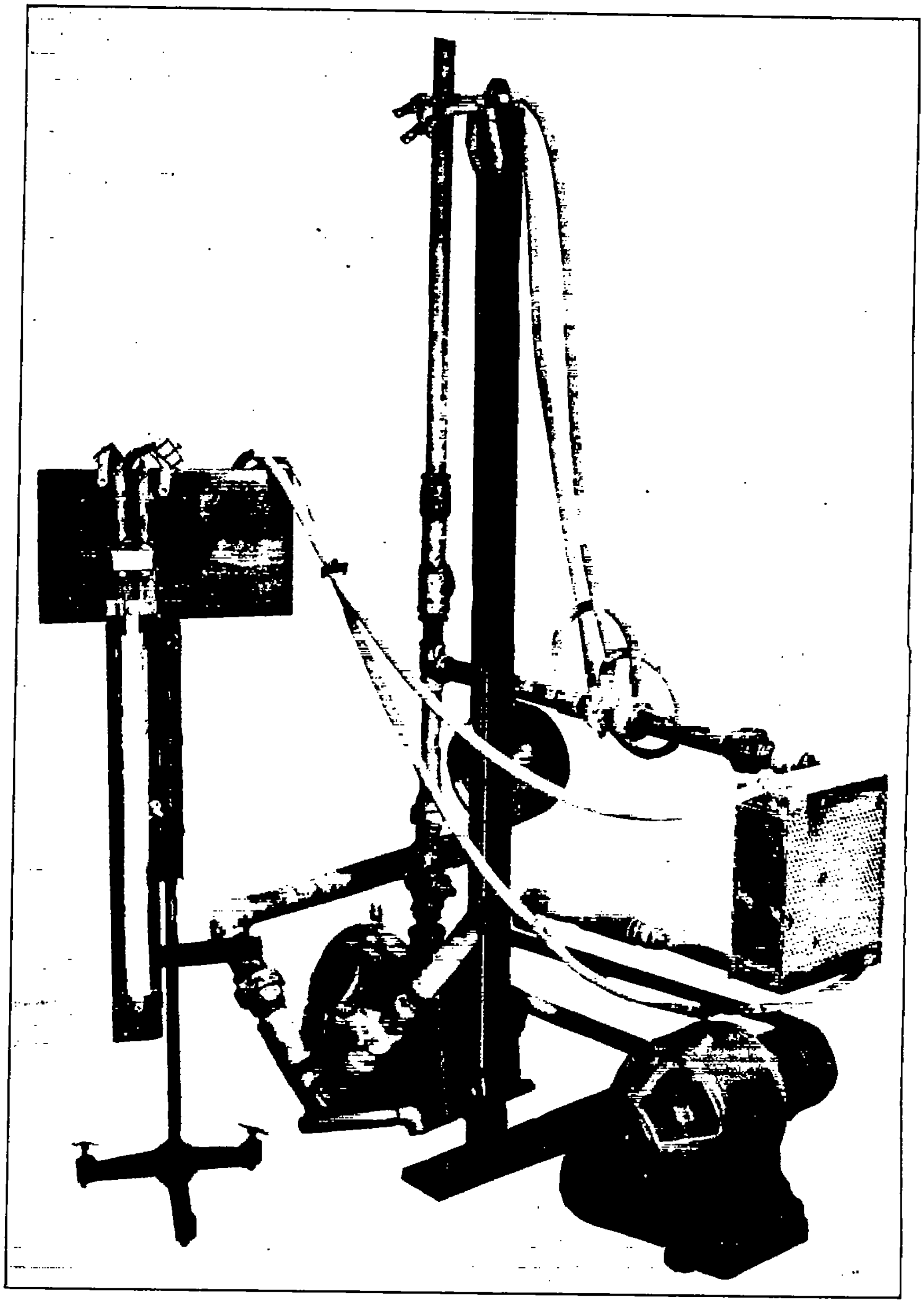
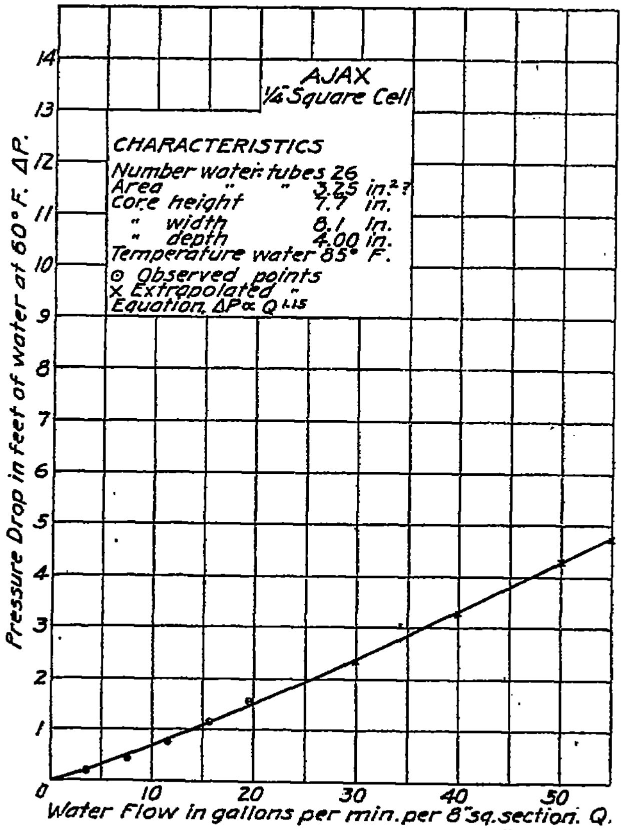
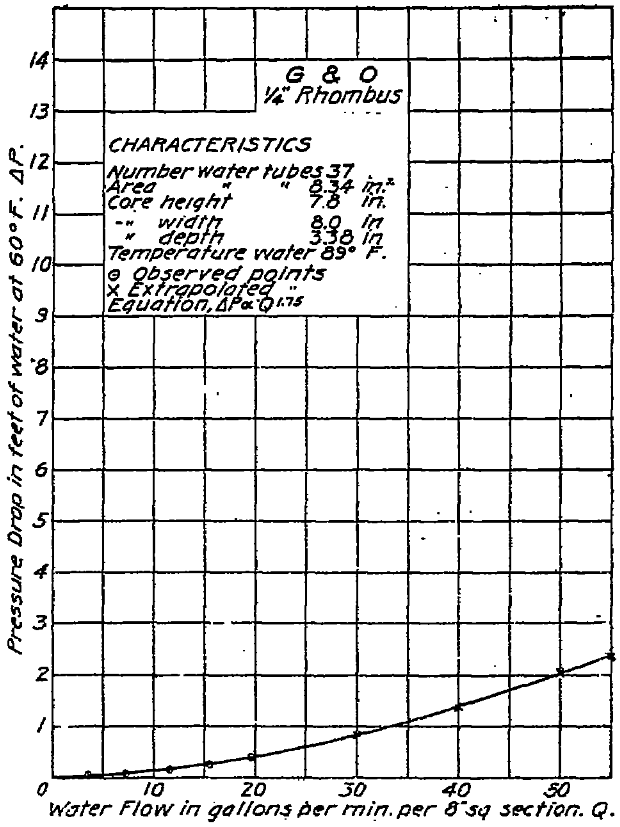
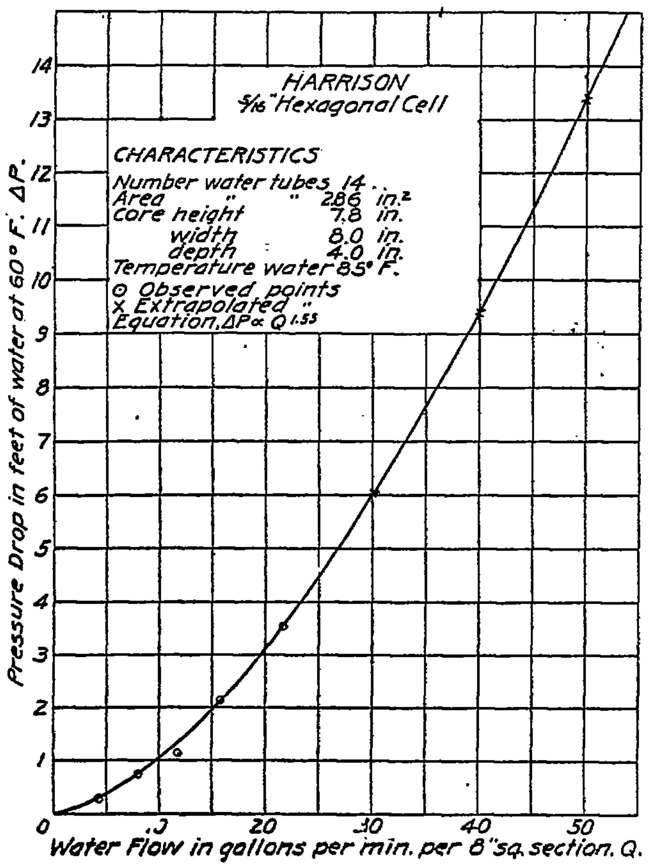
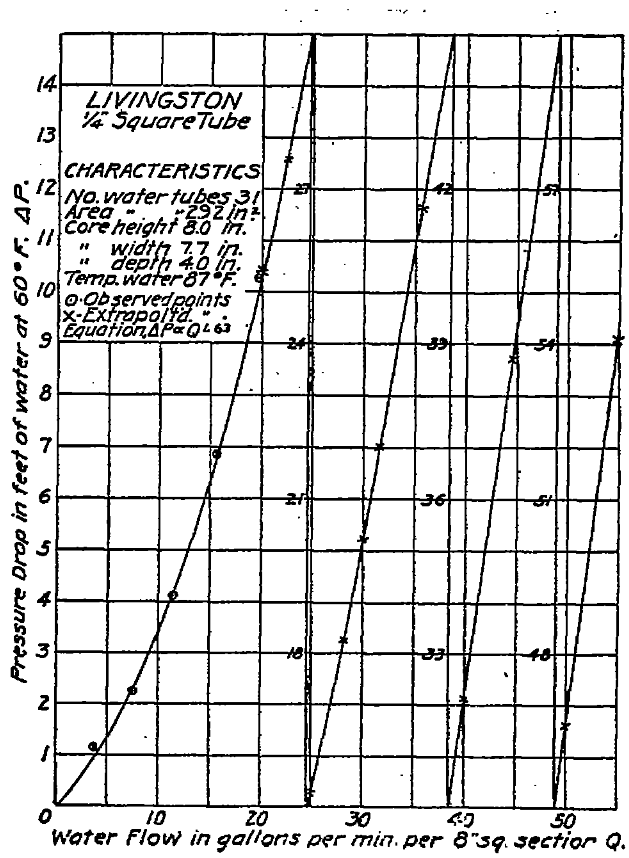


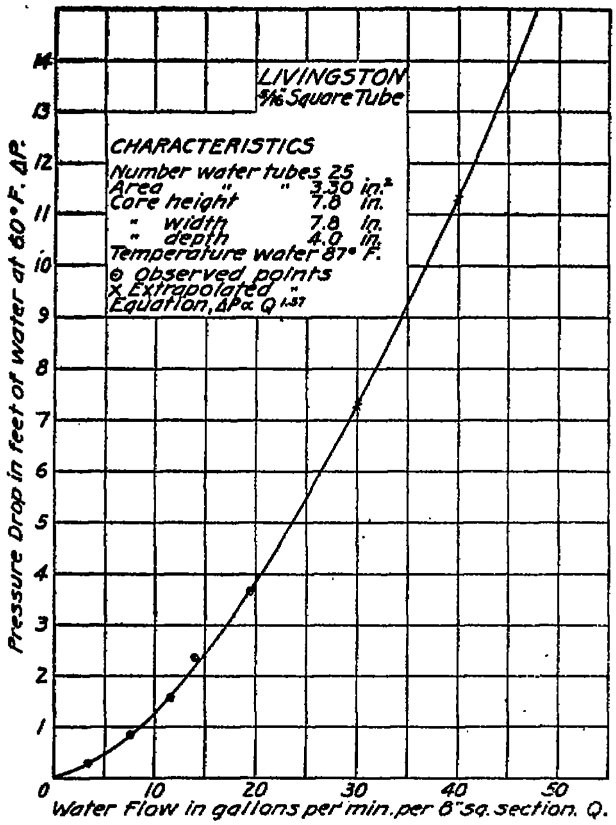
FIGURE 13.—Apparatus used to measure pressure necessary to produce water flow through radiator cores.

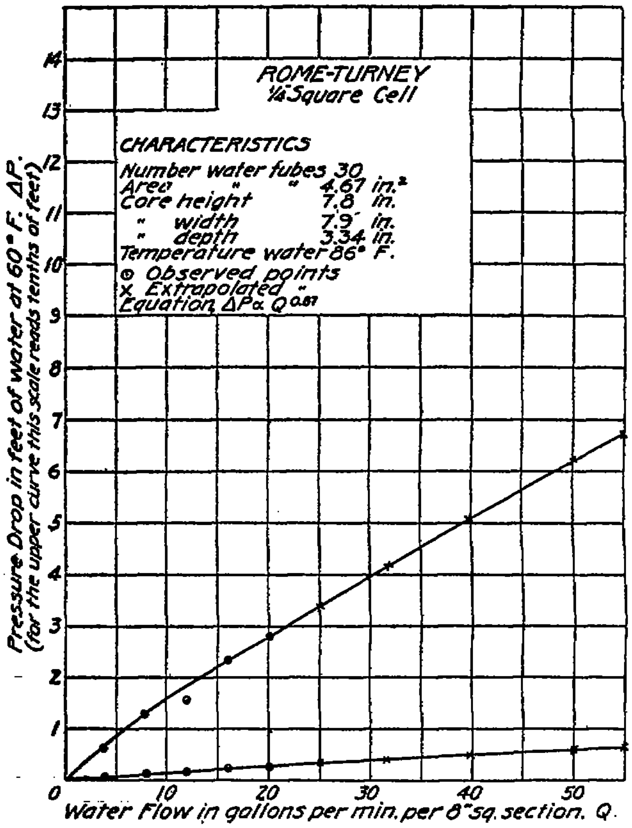

AJAX
¼" Square Cell
CHARACTERISTICS
Number water tubes 26
Area " " 3.25 in.²
Core height 7.7 in.
" width 8.1 in.
" depth 4.00 in.
Temperature water 85° F.
o Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.15
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q.

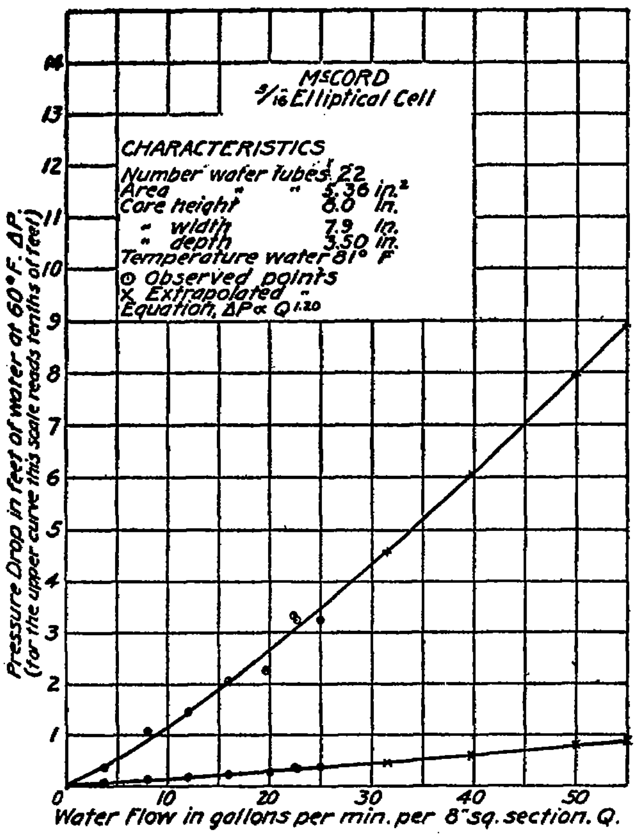

G & O
¼" Rhombus
CHARACTERISTICS
Number water tubes 37
Area " " 8.34 in.²
Core height 7.8 in.
" width 8.0 in
" depth 3.38 in
Temperature water 89° F.
o Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.75
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq section. Q.

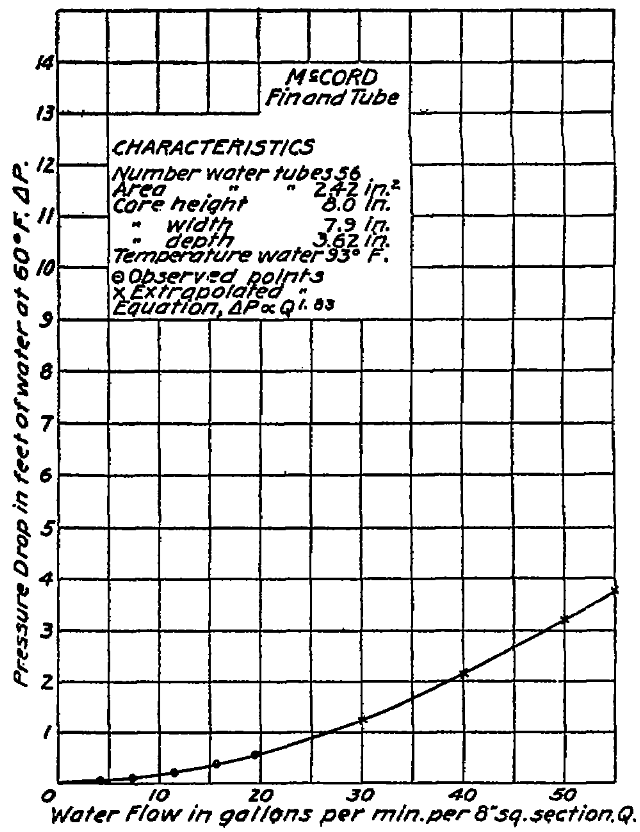

HARRISON
5/16" Hexagonal Cell
CHARACTERISTICS
Number water tubes 14
Area " " 2.86 in.²
Core height 7.8 in.
width 8.0 in.
depth 4.0 in.
Temperature water 85° F.
o Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.55
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q.

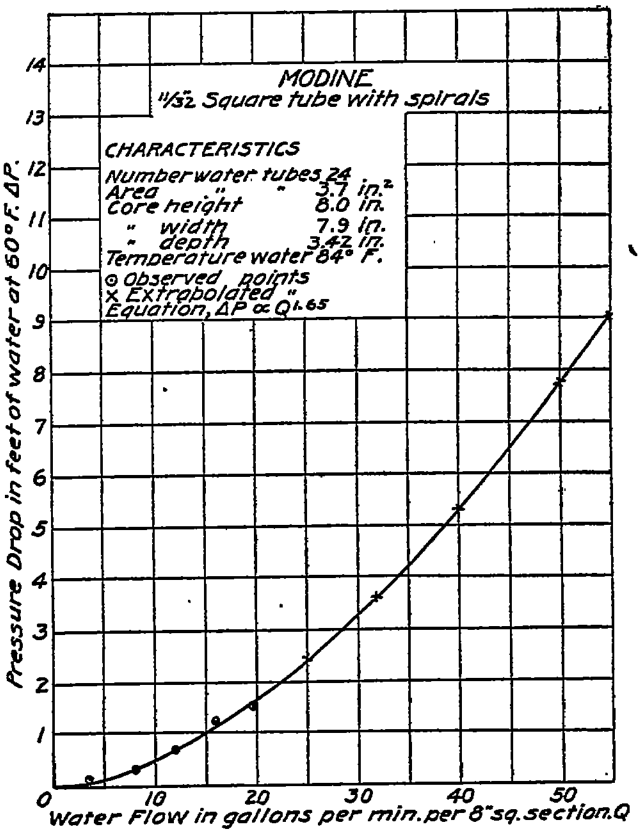

LIVINGSTON
¼" Square Tube
CHARACTERISTICS
No. water tubes 31
Area " " 2.92 in.²
Core height 8.0 in.
" width 7.7 in.
" depth 4.0 in.
Temp. water 87° F.
o Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.63
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section Q.

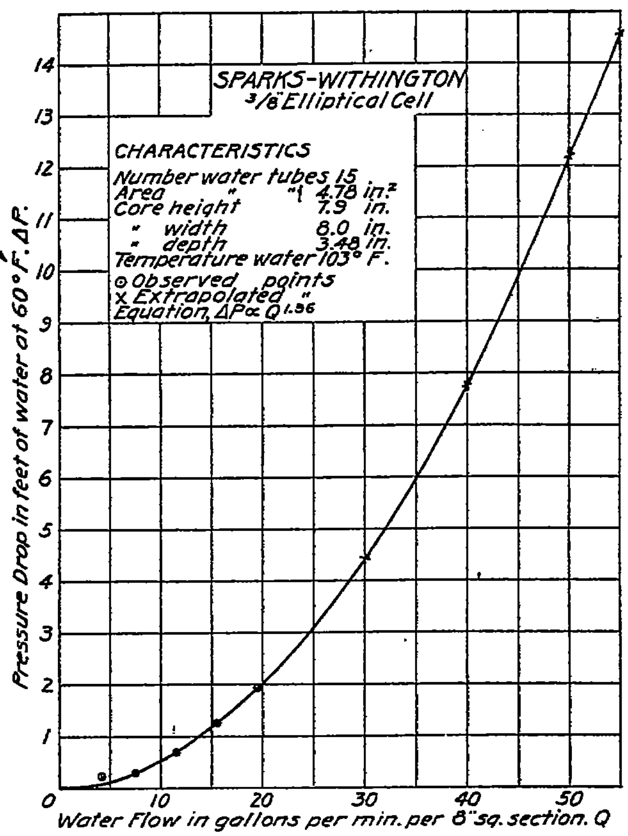

LIVINGSTON
5/16 Square Tube
CHARACTERISTICS
Number water tubes 25
Area " " 3.30 in.²
Core height 7.8 in.
" width 7.8 in.
" depth 4.0 in.
Temperature water 87° F.
⊙ Observed points
× Extrapolated "
Equation, ΔP ∝ Q^1.57
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q.

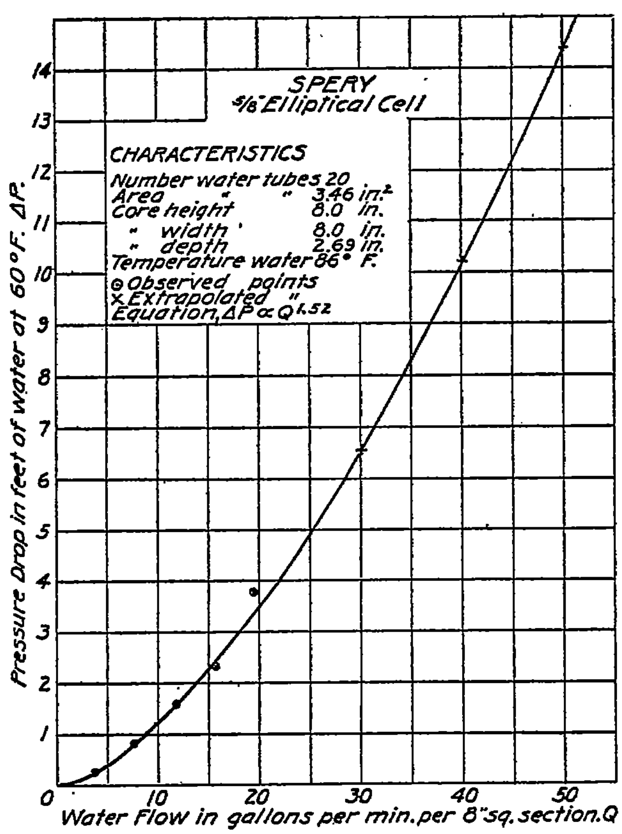

ROME-TURNEY
1/4 Square Cell
CHARACTERISTICS
Number water tubes 30
Area " " 4.67 in.²
Core height 7.8 in.
" width 7.9 in.
" depth 3.34 in.
Temperature water 86° F.
⊙ Observed points
× Extrapolated "
Equation, ΔP ∝ Q^0.87
Pressure Drop in feet of water at 60° F. ΔP.
(for the upper curve this scale reads tenths of feet)
Water Flow in gallons per min. per 8" sq. section. Q.

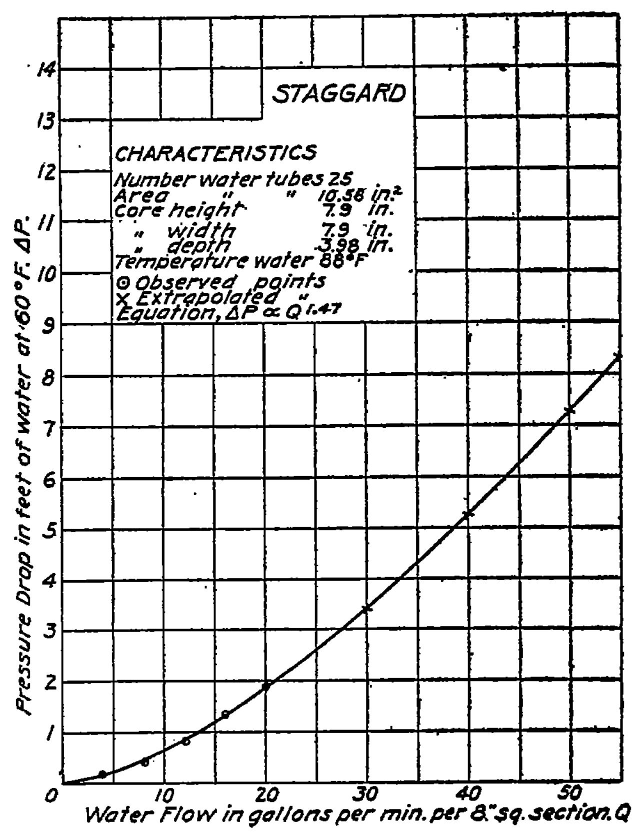

McCORD
3/16 Elliptical Cell
CHARACTERISTICS
Number water tubes 22
Area " " 5.36 in.²
Core height 8.0 in.
" width 7.9 in.
" depth 3.50 in.
Temperature water 81° F
⊙ Observed points
× Extrapolated "
Equation, ΔP ∝ Q^1.20
Pressure Drop in feet of water at 60° F. ΔP.
(for the upper curve this scale reads tenths of feet)
Water Flow in gallons per min. per 8" sq. section. Q.

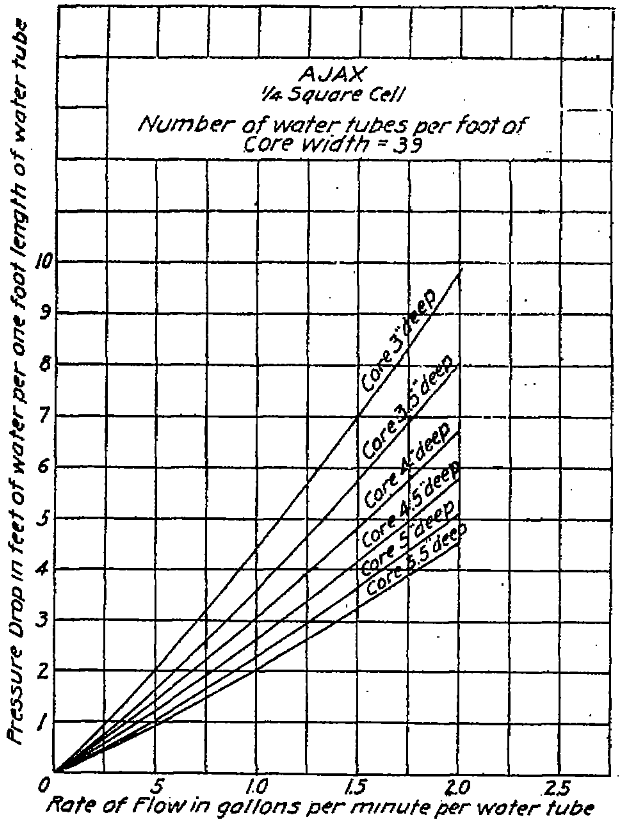

McCORD
Fin and Tube
CHARACTERISTICS
Number water tubes 56
Area " " 2.42 in.²
Core height 8.0 in.
" width 7.9 in.
" depth 3.62 in.
Temperature water 93° F.
⊙ Observed points
× Extrapolated "
Equation, ΔP ∝ Q^1.83
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q.

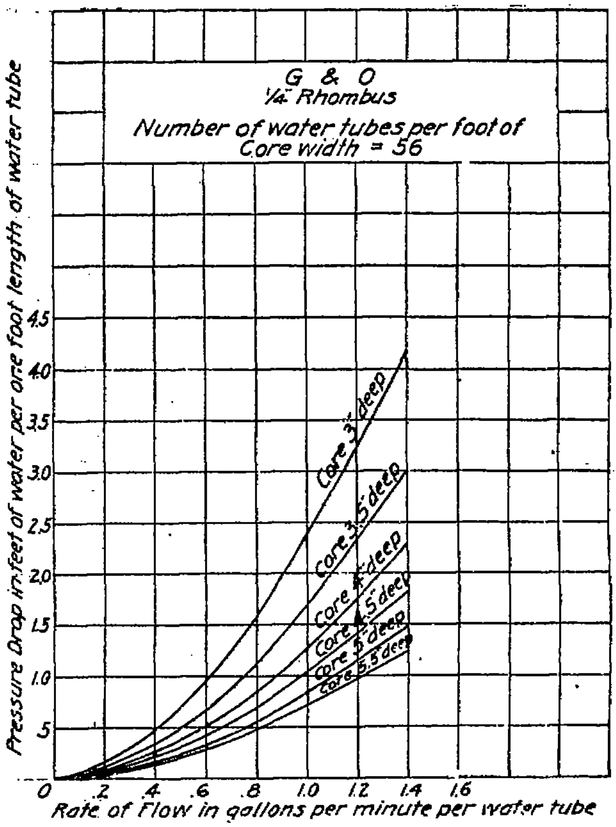

MODINE
11/32 Square tube with spirals
CHARACTERISTICS
Number water tubes 24
Area " " 3.7 in.²
Core height 8.0 in.
" width 7.9 in.
" depth 3.42 in.
Temperature water 84° F.
⊙ Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.65
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q

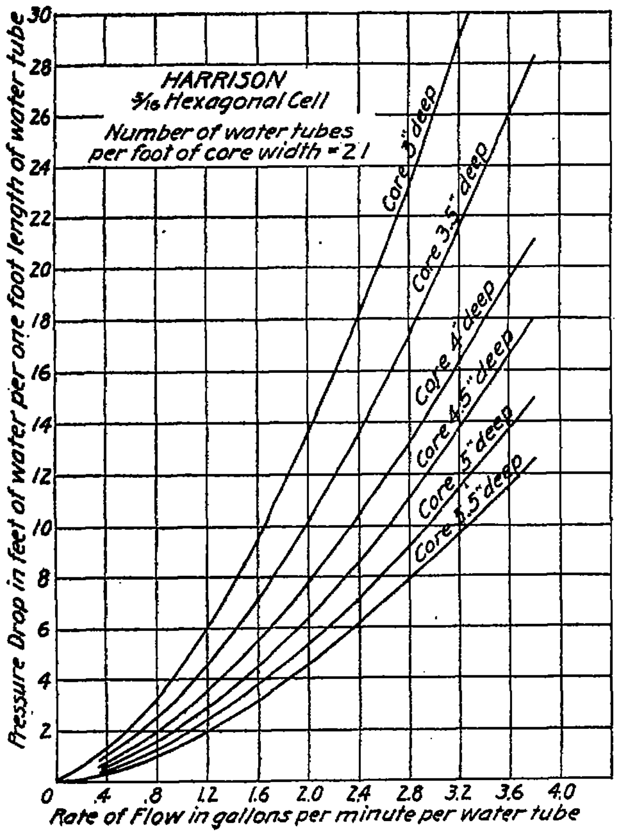

SPARKS-WITHINGTON
3/8 Elliptical Cell
CHARACTERISTICS
Number water tubes 15
Area " " 4.78 in.²
Core height 7.9 in.
" width 8.0 in.
" depth 3.48 in.
Temperature water 103° F.
⊙ Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.56
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q

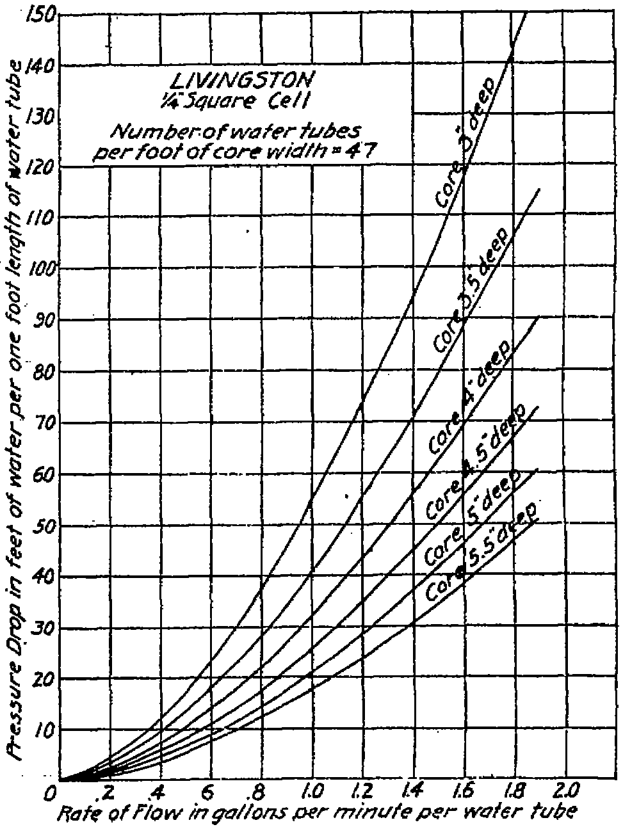

SPERY
5/8 Elliptical Cell
CHARACTERISTICS
Number water tubes 20
Area " " 3.46 in.²
Core height 8.0 in.
" width 8.0 in.
" depth 2.69 in.
Temperature water 86° F.
⊙ Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.52
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q

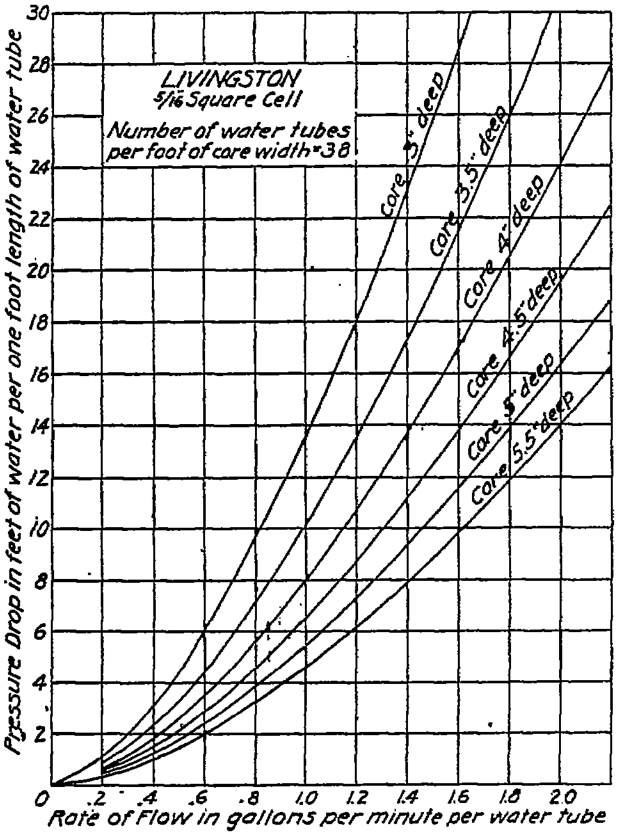

STAGGARD
CHARACTERISTICS
Number water tubes 25
Area " " 10.56 in.²
Core height 7.9 in.
" width 7.9 in.
" depth 3.98 in.
Temperature water 88° F
⊙ Observed points
x Extrapolated "
Equation, ΔP ∝ Q^1.47
Pressure Drop in feet of water at 60° F. ΔP.
Water Flow in gallons per min. per 8" sq. section. Q

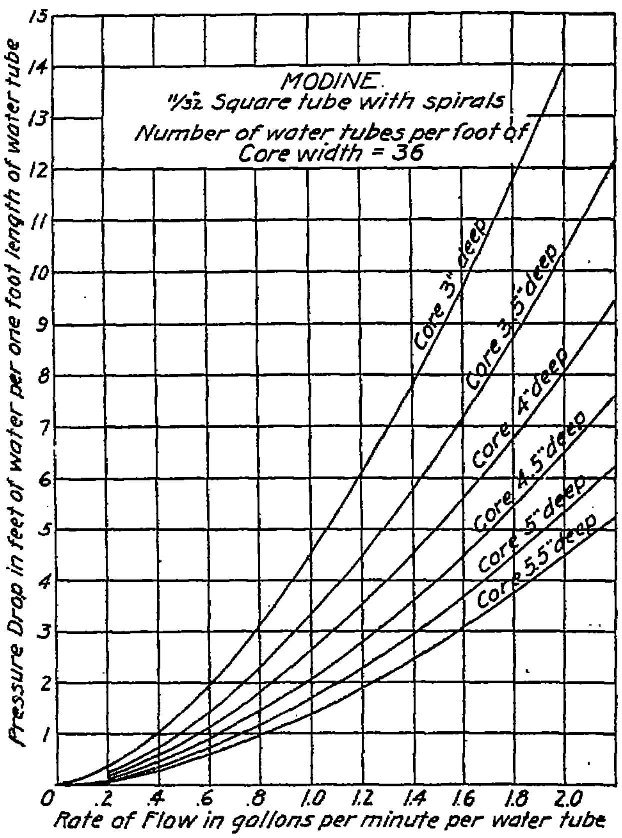

AJAX
1/4 Square Cell
Number of water tubes per foot of Core width = 39
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube

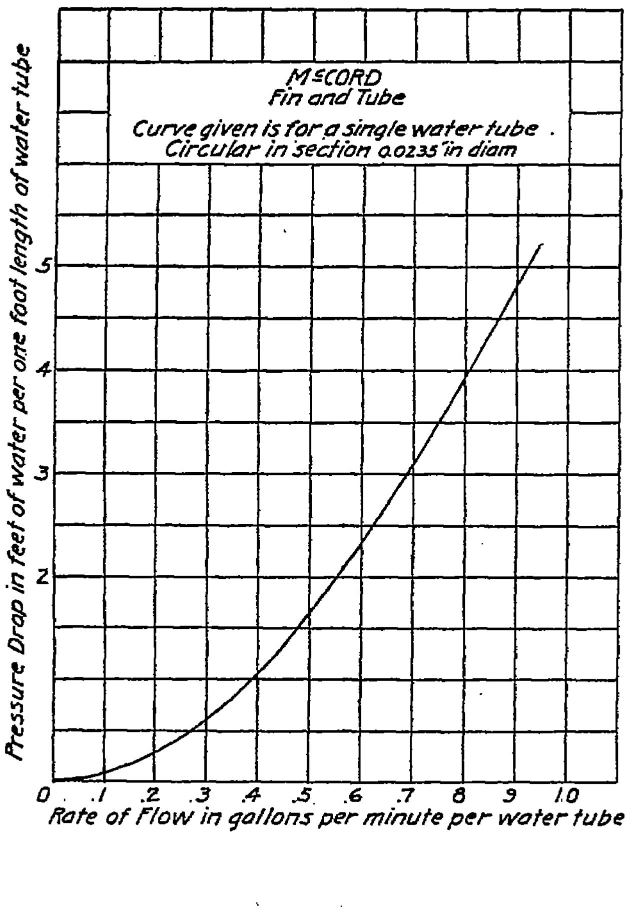

G & O
1/4" Rhombus
Number of water tubes per foot of Core width = 56
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube

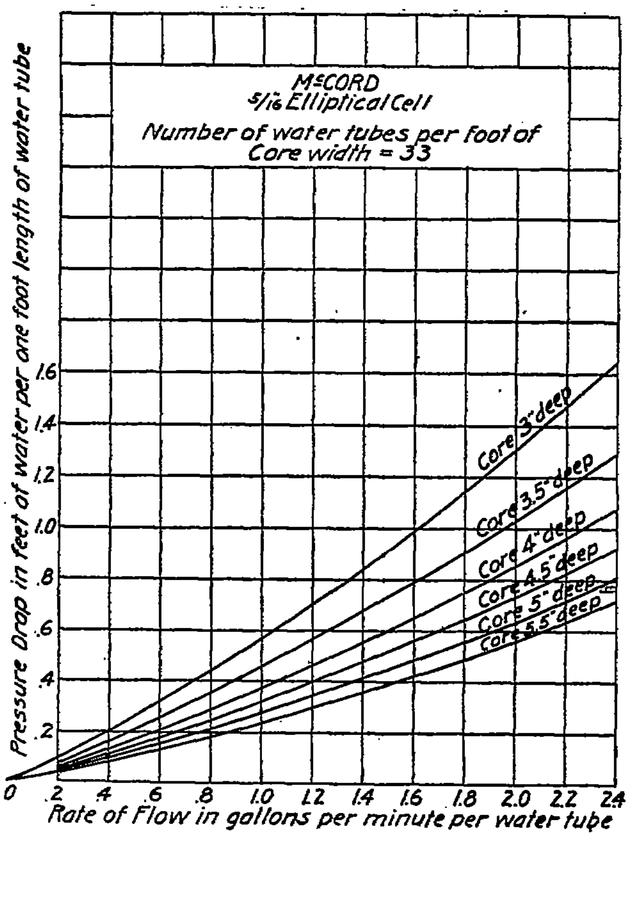

HARRISON
3/16 Hexagonal Cell
Number of water tubes per foot of core width = 21
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube

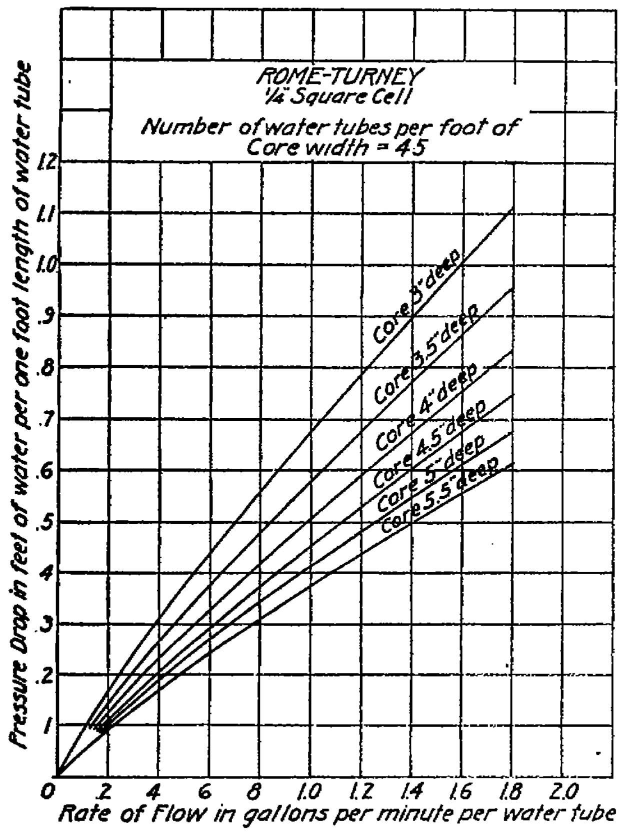

LIVINGSTON
1/4 Square Cell
Number of water tubes per foot of core width = 47
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube

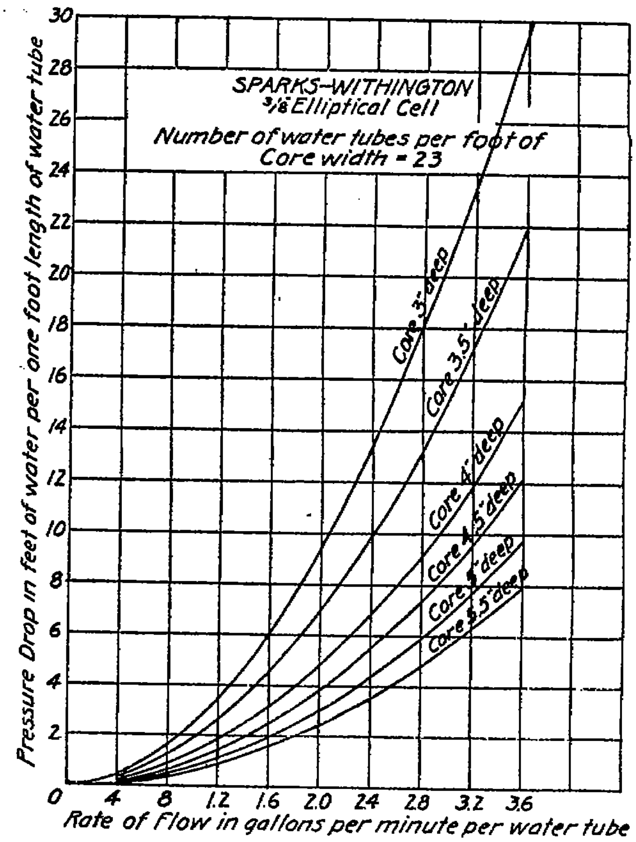

LIVINGSTON
5/16 Square Cell
Number of water tubes per foot of core width = 38
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0

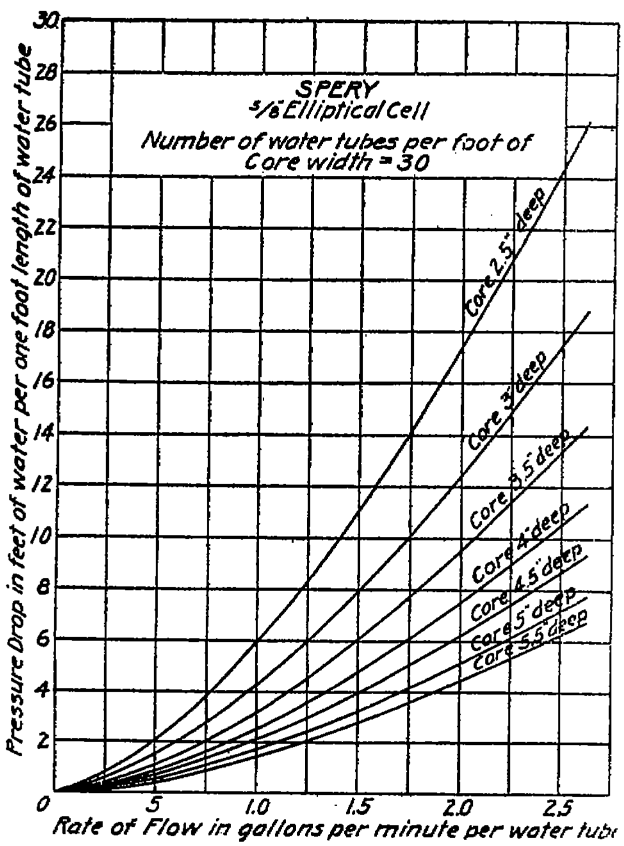

MODINE
11/32 Square tube with spirals
Number of water tubes per foot of Core width = 36
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0

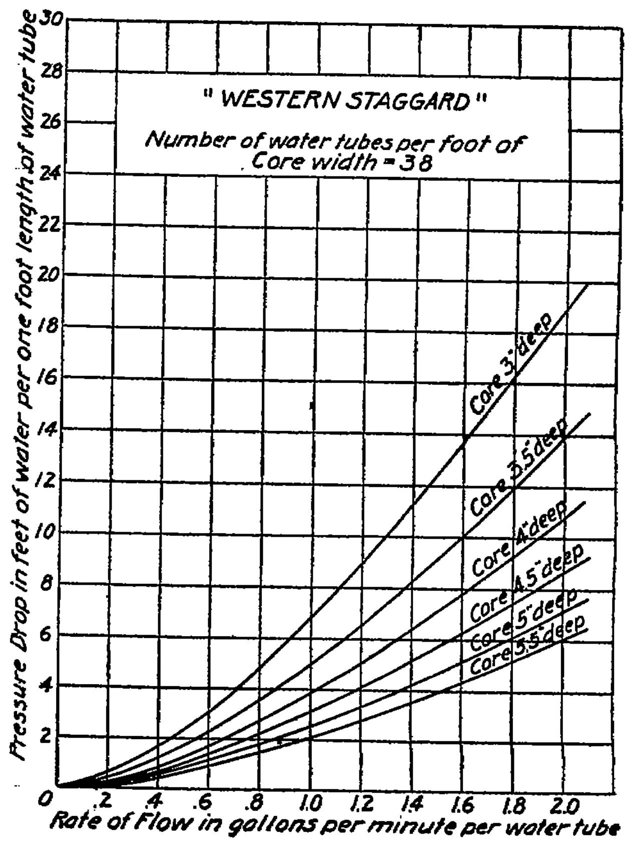

McCORD
Fin and Tube
Curve given is for a single water tube. Circular in section 0.0235 in diam
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube
2 3 4 5
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0


McCORD
5/16 Elliptical Cell
Number of water tubes per foot of Core width = 33
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube
.2 .4 .6 .8 1.0 1.2 1.4 1.6
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4


ROME-TURNEY
1/4" Square Cell
Number of water tubes per foot of Core width = 45
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube


SPARKS-WITHINGTON
3/8" Elliptical Cell
Number of water tubes per foot of Core width = 23
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube


SPERY
5/8" Elliptical Cell
Number of water tubes per foot of Core width = 30
Core 2.5" deep
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube


" WESTERN STAGGARD "
Number of water tubes per foot of Core width = 38
Core 3" deep
Core 3.5" deep
Core 4" deep
Core 4.5" deep
Core 5" deep
Core 5.5" deep
Pressure Drop in feet of water per one foot length of water tube
Rate of Flow in gallons per minute per water tube